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March 1971

A SYSTEMATIC STUDY OF THE ROUGH-WATER PERFORMANCE OF PLANING BOATS

(IRREGULAR WAVES - PART II)

by

Gerard Fridsma

This research was carried out under the
Naval Ship Systems Command
General Hydromechanics Research Program
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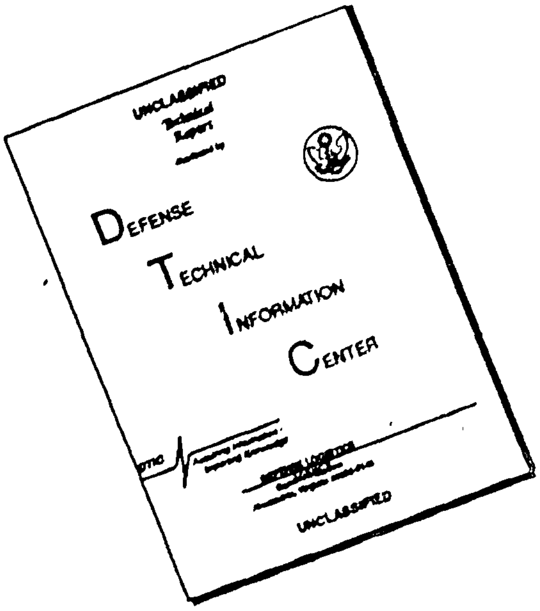

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DAVIDSON LABORATORY
STEVENS INSTITUTE OF TECHNOLOGY
Castle Point Station
Hoboken, New Jersey 07030

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P. Ward Brown, Manager
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ABSTRACT

A systematic study of the effects of deadrise, trim, loading, speed, length-beam ratio, bow section shape and sea state was made on the performance of a series of prismatic planing boat models operating in irregular waves. Measurements of the added resistance, heave and pitch motions, and impact accelerations at the bow and center of gravity served as the basis for evaluation. Statistical analysis of the results enabled direct comparisons between the independently varied parameters; and show in a quantitative way, the importance of these parameters on the rough-water performance of planing hulls. A design procedure has been developed which predicts the performance of any given hull.

Keywords

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NOMENCLATURE

b	average beam of planing hull, ft
C_v	speed coefficient, $V/\sqrt{gb}$
C_Δ	load coefficient, Δ/wb^3
d	rise of the center of gravity in smooth water, ft
g	acceleration of gravity, 32.2 ft/sec^2
$H_{1/3}$	significant wave height, ft
h	maxima of CG heave excursions from mean, ft (analogous to amplitude in S.H.M.)
$\bar{h}$	average value of h, ft
h_{50}	value of h which will be exceeded with probability of 50%, ft
h_{90}	value of h which will be exceeded with probability of 10%, ft
$h_{1/10}$	average of the 1/10 highest h values
h_{dc}	mean position of VCG relative to floating condition in rough water, ft
I	model pitch inertia, lb.in^2
k	pitch gyradius, % L
k_1	hull loading factor, $C_\Delta/L/b$
k_2	hull loading factor, $C_\Delta/(L/b)^2$
L	overall hull length, ft
LCG	longitudinal center of gravity, % L from stem
Q	probability complement, 1-P
P	probability
r	proportion of negative crests or troughs
R	resistance in smooth water, lb

R_{AW}	added resistance in waves, $R_W - R$, lb
R_W	total resistance in waves, lb
V	horizontal speed, fps
VCG	vertical center of gravity, height above keel
$V/\sqrt{L}$	speed-length ratio, knots/ft$^{1/2}$
w	specific weight of fresh water, 62.4 lb/ft^3
x	dummy variable
y	motion amplitude non-dimensionalized by root mean square value
β	deadrise angle, deg
Δ	hull displacement, lb
ϵ	factor that describes width of broad band spectra
η_{bow}	bow acceleration at a point 10% of the length aft of stem, normal to keel, g
η_{cg}	CG vertical acceleration, g
$\theta, \bar{\theta}, \theta_{50}, \theta_{90}, \theta_{1/10}$	pitch motions relative to mean, deg (see h)
θ_{dc}	mean trim of keel relative to horizontal in rough water, deg
ρ	density of fresh water, 1.94 slug/ft^3
τ	trim angle of keel relative to horizontal, deg
τ_o	static trim, deg

<u>Subscripts</u>

m or max	indicates quantities associated with the condition of maximum added resistance

INTRODUCTION

The need for information on the hydrodynamic behavior of planing hulls in rough water has already been stressed in Phase I[1] of this study. Results from the first phase, which concerned itself with regular waves, indicated very definite trends between seakeeping and systematically varied geometric and operational parameters. These findings, however, are applicable only at low speeds and small wave heights where the hull motions vary linearly with wave height. Comparison of the response operators obtained in regular and irregular waves showed the non-linear behavior of planing boats in moderate sea states and at speed-length ratios of from 4 to 6. Consequently there still remained the need to evaluate planing boat performance in the more realistic environment of moderate and large sea states.

The same models and type of test program were run in irregular waves as was done for regular. That is, constant deadrise prismatic hulls were used whose length, load, and center of gravity could be varied. It was therefore possible to investigate the effects of deadrise (10°, 20°, 30°), length-beam ratio (4, 5), load (C_{Δ} = 0.4 to 0.72), trim (4°, 6°), speed-length ratio (2, 4, 6), and sea state (significant wave height/beam ratio = 0.2 to 0.7). In addition a different bow form of more practical and conventional design was incorporated on one of the models to define the effect of section shape or bow warp. These parameters were changed systematically and independently so as to isolate a single parameter without affecting other model properties.

This study was a continuation of the Navy's interest in the small boat field and was conducted under its General Hydromechanics Research Program. (Contract N00014-67-A-0202-0010)

MODELS

The models used for the tests in irregular waves were identical to those built for the Phase I tests. The reader is referred to this reference[1] for greater detail. The three basic models incorporated constant deadrise angles of 10, 20 and 30 degrees respectively. The length of the 20° deadrise hull could be changed by inserting different transom sections on the same bow form, thus enabling tests at L/b = 4 and 5. A new bow form was constructed to study the effect of warp, currently employed on conventional planing hulls, and was made so that it faired in with one of the existing 20° deadrise transom sections. The model lines are described in Figs 1 and 2 while photographs are included in Fig 3.

The VCG was the same for all models (0.294 beams above the keel) while the LCG was adjusted by sliding a movable plate along rails built into the model. Load variations followed from the schedule given below covers a range expected in actual design. It also reflects the more probable case that load should vary as some function of the length-beam ratio. The gyradius was set at 25% of the hull length for the hull loading represented by $C_{\Delta}/L/b = 0.12$. Other loadings at the same length-beam ratio were applied at the CG so as to maintain the same pitch inertia.

Two accelerometers were installed in the model at the LCG and bow, the latter being 10 percent of the length aft of the stem. So as to insure proper separation at the chine, thin celluloid strips were taped to the sidewall of each model and projected 0.030 inches vertically down below the chine.

LOAD SCHEDULE					MODEL VALUES	
L/b	k	C_{Δ}	k_1	k_2	Δ, lb	I lb-in^2
4	.280	.384	.096	.0240	10.11	1020
"	.250	.480	.120	.0300	12.64	1020
5	.280	.480	.096	.0192	12.64	2000
"	.250	.600	.120	.0240	15.78	2000
"	.228	.720	.144	.0288	18.95	2000

APPARATUS AND TEST PROCEDURE

Smooth-Water Resistance Tests

If one is to use a parametric study for comparing the performance of planing boats in rough water, a matrix of smooth-water operating conditions must be developed. When comparing planing hulls that have different deadrise angles, it is, for example, necessary to evaluate them at the same speed, load, length-beam ratio, pitch moment of inertia, and running trim. The LCG position that a 30-deg deadrise boat requires to achieve 4-deg trim at a particular speed will be different from that required by a boat with 10-deg deadrise at the same speed. The smooth-water tests, therefore, were designed to cover a wide range of loading, speed, and LCG positions, to determine trim as a function of LCG position, thus making it possible to choose a number of specific running conditions for later investigation in waves. Most of this smooth water information was obtained previously in Phase I, leaving only a minimal test program for the current model configurations.

The tests were conducted in the Davidson Laboratory's Tank 3. The standard free-to-heave and -trim resistance carriage was used, together with a (0-20 lb) drag balance. No provision was made for the stimulation of turbulence in the boundary layer.

The rise of the CG, the trim, and the drag were measured at constant-speeds corresponding to speed-length ratios of 2, 4, and 6 at $C_\Delta = 0.38$ to 0.72, and for LCG positions at from 54 to 68 percent of the hull length aft of the stem. All models were assumed to have horizontal thrust axes passing through the CG.

Irregular Wave Tests

In the Phase I tests in regular waves, the model was allowed the freedom to surge as well as the usual freedom to heave and pitch. Visual observation and an examination of the speed time history record showed that

little surging motion took place, particularly at speed-length ratios of 4 and 6. At the beginning of the present investigation, it was decided to investigate the effect of surge freedom at a speed-length ratio of 2, by comparing the results obtained from "constant thrust" and "constant speed" tests of the same model at identical conditions. A method was devised whereby the servo carriage could be locked in position by coupling it to a drag dynamometer. Two integrating digital voltmeters (IDVM) were used to measure the average drag force in waves; the one performing an integration of the drag vs. time record and the other simultaneously measuring the time between two positions in the tank during which the integration took place. A simple division produced the average drag. Evaluation of the added resistance, motions, and accelerations showed that for planing hulls, freedom in surge had little effect on the results (see Appendix 1) Consequently, all remaining tests were made at constant speed.

The models were tested in irregular waves having significant wave heights of 2, 4, and 6 in. or 0.222, 0.444, and 0.667 beams; at speed-length ratios of 2, 4, and 6; with deadrise angles of 10, 20 and 30°, with length-beam ratios of 4 and 5; with smooth water running trims of 4 and 6°; and displacements corresponding to C_Δ's of 0.38 to 0.72. Time histories were taken of the heave and pitch motions, bow and CG acceleration, wave profile, speed and drag force; and recorded simultaneously on oscillograph paper and analog magnetic tape. Enough runs were made at each speed-length ratio and test condition so as to obtain a statistical sample of at least 75 wave encounters. In the majority of cases, the sample size exceeded 100 such encounters. The irregular wave program in Tank No. 3 generates Pierson-Moskowitz Sea Spectra; those used for these tests are shown in Fig 4. Table I lists the model configurations. Additional details of the test setup can be found in Phase I.[1]

RESULTS

Smooth-Water Tests

Most of the smooth water results have been previously presented in Phase I and are not repeated herein. For the specific model configurations chosen to be tested in waves, the smooth water characteristics are included in Table I.

Irregular-Wave Tests

The rough water data is tabulated in Tables II (resistance), III (heave), IV (pitch) and V (acceleration) and were obtained from analysis of the time history oscillograph records. These records were hand read over the constant speed portion of each run by recording the magnitude of all maxima and minima of the motions and the positive acceleration peaks. The frequency response of the model and instrumentation were examined, and the acceleration time histories were processed in such a way so as to insure the reporting of strictly rigid body accelerations (the hull being assumed to experience zero "g" at rest on the water). The data was analyzed statistically to obtain histograms, cumulative frequency, and probability plots of the data.

In general, the motions followed a "distorted Rayleigh" distribution, in which the amount of distortion is given by the parameter, r. This two parameter distribution can be characterized by the value of r and the average; or equivalently, in the case of motions, by the 50 and 90 percent probability levels. Both of these levels relative to the mean are included in Tables III and IV, along with the r value, average, and d.c. component.

The accelerations were handled statistically in the same fashion as the motions and were found to be distributed according to a simple exponential rule. To describe this one parameter distribution all that is needed is the average peak acceleration which is recorded in Table V.

From these tabulations, the effects of various hull parameters on planing boat performance can be determined. We have chosen to summarize this data in the form of design charts which are described in a subsequent section. These charts will reproduce the values given in the table and can also be used for design studies and performance prediction.

ANALYSIS

The handling of data information obtained from an irregular wave requires the use of statistical methods in order to show the dependence of the average acceleration, for instance, on the test parameters such as hull loading, speed, and significant wave height. For linear systems, spectral analysis is a useful tool and is associated with the Response Amplitude Operator (RAO) which becomes the primary means of describing behavior and the basis for comparing one configuration with another.

The planing boat, however, behaves in a non-linear fashion over the greater part of its operating range and consequently spectral analysis cannot be used. Instead, the amplitudes of the time history responses were taken from the oscillograph records; and an effort was made to describe their distribution. This technique reduces a great deal of statistical information to a small number of overall properties which indeed characterize the responses. They are then useful in comparing the performance of one hull configuration with another, or the same hull at different speeds and in different sea environments.

The same sort of approach is used, for example, in taking a time history of an irregular sea surface, and describing it as a narrow band wave spectrum having a zero mean Gaussian distribution for its elevations and a Rayleigh distribution for its wave heights. By knowing the standard deviation, both of these distributions are uniquely defined by mathematical expressions. Differences between sea states can therefore be made on the basis of their average or significant wave heights.

The motion and acceleration time histories were analyzed in this fashion, and assumed theoretical distributions were successfully applied

to the experimental data. A sample size of about 100 peak amplitudes was taken for each running condition in order to have some confidence that 99% of the population had been covered.

Heave and Pitch Motions

The motion amplitudes about the mean may be described by a probability function given by the so-called "distorted Rayleigh function." The function is derived by Rice[2] in connection with finding the distribution of maxima arising from a broad frequency spectrum. Longuet-Higgins[3] gives additional and more useful details of this statistical distribution and shows that the distribution is dependent on two parameters; the root-mean-square value and a parameter ϵ, which is a measure of the relative width of the spectrum. The value of ϵ is obtained from experiment by measuring the proportion, r, of negative maxima. Once determined, the distribution is unique when the motion amplitudes are normalized by their mean-square value. Details of the distribution are presented in Appendix II.

In deciding whether or not experimental data fits a given distribution, it is convenient to use specially ruled grid paper, that forces a particular probability function to plot as a straight line. This paper is available, for example, for normal distributions and extreme-value distributions. Semi-logarithmic paper will reduce the exponential and Rayleigh distributions to a straight line when the variable or variable squared is plotted on the linear scale respectively. For the distribution which describes the maxima of a broad frequency spectrum, it is not practical to use special paper since the grid would change for each value of ϵ. Instead the experimental value of the peak motion is compared to the theoretical normalized value of the peak motion at the same corresponding probability and r value. When plotted on rectangular grid paper, the result should be a straight line through the origin if the assumed distribution is correct. The slope of the line is directly related to the standard deviation or rms value of the motions.

Calculation procedure for heave and pitch motions.

Given a sample of crests and troughs representing maxima and minima from some known reference which has been put on file in a computer.

A. The average crest and trough is computed for each run.

B. The mean value is computed. This quantity is defined as being mid-way between the average crest and average trough. The mean represents a d.c. shift in the time history between a static reference at zero speed and the average value when underway at speed. For the heave, this is the average rough water rise of the center of gravity from the planing hull's floating position. For pitch this is the average rough water attitude of the keel relative to the smooth water surface.

C. The crests and troughs are then computed relative to the mean. Each of the runs having the same test conditions are placed in a common file and the crests and troughs sorted in ascending order.

D. The sorted information (X_i) is then grouped in about 14 intervals; the proportion r of negative maxima or minima determined, and the number of motion values in each interval obtained.

E. The machine then computes the cumulative frequency and corresponding probability that a maxima or minima is less than or equal to the interval value.

F. From the probability and r values, the theoretical value of the normalized amplitude (y) is calculated.

G. After plotting X_i vs. y, the data is compared with the line drawn through the origin, $x = y = 0$, and the point, $x = \bar{x}$, $y = \bar{y} = \sqrt{\pi/2}(1-2r)$. This latter value is obtained from the first moment of the probability distribution taken about the origin (see ref. 3). Some typical examples are shown in Figs 5 and 6.

Accelerations

The peak accelerations were found to follow a simple exponential distribution. It is a one parameter distribution that is uniquely determined from the average value (see Appendix II).

The experimental data, which includes all positive peak accelerations, including those that are wave-induced as well as impact spikes, are sorted, grouped, and processed as in steps C, D, and E above. The probability of exceeding acceleration η is plotted vs. η on semi-log paper. The result should be a straight line going through the origin and the point $P = .632$, $\eta = \bar{\eta}$. Some typical examples are described in Fig 7.

Final Evaluation

All distributions were plotted and compared with the assumed theoretical distribution. Although there were a number of exceptions, in general, all agreed quite well. The information tabulated for the motions included the average crest or trough from the mean, the mean itself (d.c. shift), r , and two points of the distribution, namely the 50% and 90% probability points. For the accelerations, only the average peak value is recorded.

The question may arise as to how one would obtain motion or acceleration information at other than the prescribed conditions reported herein. A designer might be interested in the values which would only be exceeded 1% of the time or be concerned with the 1/3 or 1/10 highest values. For the motions, these values are linearly related to y_{99} or $y_{1/3}$ or $y_{1/10}$. Thus once an r is obtained from the tables plus one point on the straight line relating the motions with y , the other motion quantities are determined by direct proportion. The expressions for y such as $y_{1/3}$ must be solved numerically and the reader is referred to ref. 3. A few of the more common y values are plotted as a function of r in Appendix II.

For the 1/3 or 1/10 highest accelerations, the designer has only a simple calculation to make by knowing the average value and distribution. Plots of the appropriate expressions are included in Appendix II.

Having established an analytical procedure for treating the data, a comparison could now be made among the various hull parameters based on the properties of the distribution. For the motions, the one-tenth highest values were used to evaluate one configuration against another. The model heave was non-dimensionalized on the basis of beam; and the tabulated 90% probability values for heave and pitch were multiplied by the ratio of $y_{1/10}/y_{90}$, which is approximately = 1.22 over the r value range. For the accelerations, the average tabulated values were used. The one-tenth highest accelerations can be obtained by multiplying through by 3.30. The results have been incorporated in design charts and will be described in the next section.

DESIGN CHARTS

The ultimate goal for this study is to enable designers and those interested in planing craft to use the information gathered herein in a practical and meaningful way. Working charts, with appropriate correction factors, (Figs 8-21) were constructed so that the results could be immediately applicable to the prediction of full scale performance of planing hulls. Some details of the effects of individual parameters can be gleaned from the charts and equations; but this is discussed in the next section in a more generalized way. In this section the reader will be shown how to use these charts, and what corrections are applicable, as well as a number of worked examples.

To enter the charts and determine a prediction for a given boat, seven quantities must be known; namely displacement, overall length, average beam, average deadrise, speed, smooth water running trim and the significant wave height of the irregular sea. Since realistic boats do not normally have a constant beam or deadrise, it is suggested that these quantities be averaged over the aft 80% of the boat. It is understood that the designer has recourse to smooth water prediction methods (ref. 4) which will enable an estimate to be made for the resistance, trim, and rise of the center of gravity as a function of forward speed.

The non-dimensional parameters are calculated next, such as C_Δ, L/b, $V/\sqrt{L}$, and $H_{1/3}/b$.

In using the charts, the designed should be careful not to make gross extrapolations. The charts are accurate within the ranges of test data. A reasonable amount of extrapolation has been built into the charts beyond the limits of the test data; and the results continue to be reliable. It is when parameters go far beyond the test ranges that one must be careful. The guide below should be helpful in establishing the limits of the use of the charts.

Parameter	C_Δ	L/b	C_Δ/L/b	τ	β	$H_{1/3}/b$	$V/\sqrt{L}$
Range	.3-.9	3-6	.06-.18	3°-7°	10°-30°	to 0.8	to 6

A. Added Resistance in Waves (Figs 8 and 9)

The chart in Fig 8 is entered with a given trim and deadrise. $(R_{AW}/wb^3)_{max}$ and $(V/\sqrt{L})^*_{max}$ are read off for the three sea states. An interpolation for the correct sea state can be made immediately; or the added resistance can be obtained as a function of wave height. For a given $V/\sqrt{L}$ or a series of speeds, the ratio V/V^*_{max} is calculated, and $R_{AW}/R_{AW_{max}}$ obtained from Fig 9. The added resistance is found by multiplying the resistance ratio of Fig 9 by the $R_{AW}/wb^3)_{max}$ obtained from Fig 8. The result, however, is true for a $C_\Delta = 0.6$ and $L/b = 5$, and must be corrected by means of the following formulas

$$(R_{AW}/wb^3)_{final} = (R_{AW}/wb^3)_{charts} \times E\ (C_\Delta, L/b, V/\sqrt{L}, H_{1/3}/b)$$

ADDED RESISTANCE CORRECTIONS

$V/\sqrt{L}$	E	Equation
2	$1 + \left[\frac{(L/b)^2}{25} - 1\right] \Big/ (1+.895(H_{1/3}/b - 0.6))$	(1)
4	$1 + 10\ H_{1/3}/b(C_\Delta/L/b - .12)$	(2)
6	$1 + 2\ H_{1/3}/b \left[.9(C_\Delta-.6)-.7(C_\Delta-.6)^2\right]$	(3)

For the particular values of C_Δ and L/b, calculate E and plot as a function of $V/\sqrt{L}$. Read off E at the $V/\sqrt{L}$ of interest to correct the added resistance value.

* $(V/\sqrt{L})_{max}$ or V/V_{max} are associated with the speed at which $(R_{AW})_{max}$ occurs.

B. Motions (Figs 10-14)

The design procedure for the motions are incorporated on five charts. These charts will give the correct values for the 1/10 highest motions (crests) at the specified load, length/beam ratio, and sea state but for a trim of 4° and deadrise of 20°. Corrections for trim and deadrise are then applied to obtain the final values. Figures 10, 11 and 12, and 13 and 14 are for speed length ratios of 2, 4, and 6 respectively. Interpolation for speed will be done as a last step.

Enter Figs 10-14 at a specified sea state for the particular C_{Δ} of interest. Three values of the heave and pitch will be obtained for each of the three speeds. This must be done for both $L/b = 4$ and 5. Interpolate for correct L/b by a straight line approximation. The results must be corrected by means of the following formulas

$$(h_{1/10}/b)_{final} = (h_{1/10}/b)_{charts} \times F(\tau, V/\sqrt{L}) \times G(\beta, V/\sqrt{L})$$

MOTION CORRECTIONS

	Formula	Equation
Trim	$F = 1 + \frac{V/\sqrt{L}}{24}(\tau - 4^{\circ})$	(4)
Deadrise	$G = .56 + .11V/\sqrt{L} + .11(\frac{\beta}{10})^2(1 - \frac{V/\sqrt{L}}{4})$ $= 1 \quad V/\sqrt{L} \leq 4$ $= G \quad V/\sqrt{L} \geq 4$	(5)

After applying trim and deadrise corrections, plot the heave and pitch values against $V/\sqrt{L}$ and interpolate for correct speed. Repeat procedure for other sea states.

C. Accelerations (Figs 15-21)

Seven (7) charts are presented to obtain the average C.G. (Figs 15-17) and bow (Figs 18-21) accelerations. Individual plots are provided for each speed ($V/\sqrt{L} = 2, 4, 6$) and length/beam ratio ($L/b = 4, 5$). Accelerations are obtained for the correct load, at a specified sea state. After interpolation for L/b, corrections are applied for trim and deadrise.

Enter Figs 15-17 and obtain three values of the C.G. acceleration at each of the three speeds for a given $H_{1/3}/b$ and C_Δ. Do for both L/b = 4 and 5. Repeat in Figs 18-21 for bow acceleration. Plot the acceleration against $(L/b)^2$ and interpolate for correct length/beam ratio.

The results are corrected for trim and deadrise by the following formula

$$\eta_{final} = \eta_{charts} \times \left[\frac{\tau}{4^o}(5/3 - \frac{\beta}{30^o}\right] \qquad (6)$$

A bow acceleration correction may be applied for increased deadrise (warp) at the bow by taking 85% of the final values. This latter correction may vary with bow shape.

With corrections applied, interpolate results for given speed and repeat procedure for other sea states.

D. Summary

The procedure and corrections necessary to make full scale performance predictions and which have been described above are incorporated in Appendix III on a detailed work sheet giving step-by-step method.

E. Worked Examples

<u>No. 1</u>: Determine the added resistance, motions, and accelerations for the model condition: $\beta = 20^o$, $\tau = 4^o$, L = 45'', b = 9'', Δ = 18.95 lb, V = 13.06 fps, $H_{1/3}$ = 4''

a) The parameters are calculated

$wb^3 = (62.4)(.75)^3 = 26.3$

$L/b = 45/9 = 5$

$C_\Delta = \Delta/wb^3 = 18.95/26.3 = .72$

$V/\sqrt{L} = \frac{13.06}{1.689} / \sqrt{45/12} = 4$

$H_{1/3}/b = 4/9 = .444$

$1/C_\Delta = 1/.72 = 1.39$, $1/C_\Delta^2 = 1/(.72)^2 = 1.93$

$C_\Delta/L/b = .72/5 = .144$

b) Added resistance

For $\beta = 20^o$ and $\tau = 4^o$, from Fig 8

	$H_{1/3}/b$ .2	.4	.6
$(V/\sqrt{L})_{max}$ =	4.0	4.2	4.2
$(R/wb^3)_{max}$ =	.025	.043	.051
$(V/V_{max}) = 4/(V/\sqrt{L})_{max}$ =	1.00	.95	.95
From Fig 9, (R/R_{max}) =	1.00	.99	.98
Therefore $R/wb^3 = R/R_{max} \times (R/wb^3)max$ =	.025	.0425	.0500
From Eq. (2), E =	1.050	1.096	1.145
$(R/wb^3)_{final} = E \times (R/wb^3)_{charts}$ =	.0262	.0465	.0573

From a plot of R/wb^3 vs. $H_{1/3}/b$, the value at $H_{1/3}/b$ of 0.444 = .0493. In model pounds the resistance is .0493 x 26.3 = 1.29 lb. The actual measured value was 1.28 lb (condition 41).

c) Motions

From Fig 11, the 1/10 highest heave motions at $1/C_\Delta = 1.39$ and $H_{1/3}/b = .444$ is $h_{1/10}/b = .240$ at L/b = 5. Similarly the pitch = 4.6^o (Fig 12).

There is no correction for trim or deadrise.

The motions at the 90% points are found by dividing by 1.22 (see Appendix II).

$\therefore$ $h_{90}/b = .197$, $\theta_{90} = 3.77^o$ or in absolute units $h_{90} = 1.77$ in., $\theta_{90} = 3.8^o$. This compares with the measured values of 1.69 in. and 4.2^o.

d) Accelerations

The C.G. acceleration from Fig 16 at L/b = 5, $1/C_\Delta^2 = 1.93$, and $H_{1/3}/b = .444$ is .52 g . The bow acceleration from Fig 20 is found similarly and is = 1.70 g . These are the final values since the correction factors are unity. Therefore to nearest 1/10 of a g . $\bar{\eta}_{cg} = 0.5$ g and $\bar{\eta}_{bow} = 1.7$ g . This compares well with the measured values of 0.4 and 1.7.

<u>No. 2</u>: Determine the performance of an actual planing hull. In ref. 5 Model 2387-1 was tank tested in irregular seas. From the lines plan, the beam and deadrise is averaged over the aft 80% of the boat $\bar{\beta} = 18^{o}$, $\bar{b} = 11.2'$. The boat displaces 55,000 lb, has an overall length of 52 ft and its trim is 5.2^{o} when running at 29 knots in smooth water. The model of this boat was tested in a Sea State 3 and 5, equivalent to significant wave heights of 3.8 and 8.5 ft respectively. The performance is evaluated on the work sheet that follows.

The added resistance in waves is plotted vs. $H_{1/3}/\bar{b}$ and the values at 0.34 and 0.76 recorded; namely, $R_{AW}/w\bar{b}^3$ = .037 (SS 3) and .054 (SS 5). This compares rather well with the actual measured values of .025 and .052 taken from ref. 5.

The 1/10 highest heave amplitude can be calculated in full scale feet by multiplying through by the average beam. Also the average heave amplitude can be predicted by attenuating the above value by the ratio of $\bar{Y}/Y_{1/10}$ from Appendix II. Thus the average and 1/10 highest heave amplitudes in full scale feet are 0.9 and 2.2 respectively. This compares well with the measured values of 0.8 and 1.6 ft. Repeating the procedure for Sea State 5 yields for the average and 1/10 highest heave amplitudes 2.1 and 5.2 feet (predicted) versus 2.7 and 4.8 feet (measured). The pitch motions were not measured in the tests on Model 2387-1.

The bow acceleration must be compared at the same longitudinal station. Since the accelerometer on Model 2387-1 was mounted 25% LBP aft of the forward perpendicular, a linear correction was applied between the C.G. and bow locations. The final average bow acceleration at 25% LBP is therefore 1.3 g . The 1/10 highest acceleration is simply 3.3 times the average. After going through a similar procedure for a Sea State 5, the following comparison between predicted and measured accelerations can be made.

		η_{cg}		η_{bow}	
		average	1/10 highest	average	1/10 highest
SS 3	Predicted	0.6	2.0	1.3	4.3
	Measured	0.6	1.7	1.3	3.5
SS 5	Predicted	1.0	3.3	2.1	6.9
	Measured	-	-	2.6	6.5

Both for the C.G. and bow accelerations the predictions are in very good agreement.

PLANING HULL PERFORMANCE

WORK SHEET

I. TABULATE GIVEN INFORMATION

Δ , Displacement, lb
L , Overall length, ft
$\bar{b}$, Average beam, ft
$\bar{\beta}$, Average deadrise, deg
V , Speed, kts
τ , Smooth Water running trim, deg
$H_{1/3}$, Significant wave height, ft

Δ	L	$\bar{b}$ *	$\bar{\beta}$ *	V	τ	$H_{1/3}$
55,000	52	11.2	18	29	5.2	3.8
						8.5

*Averaged over aft 80% of boat

II. CALCULATE PARAMETERS

$w\bar{b}^3 = 89,800$
$1/C_\Delta = 1.64$
$1/C_\Delta^2 = 2.7$
$C_\Delta L/\bar{b} = .133$

	C_Δ	$L/\bar{b}$	$\bar{\beta}$	$V/\sqrt{L}$	τ	$H_{1/3}/\bar{b}$
Limits	.3-.9	3-6	10-30	0-6	3-7	0-.8
	.61	4.6	18	4.0	5.2	.34
						.76

III. ADDED RESISTANCE

A. At given $V/\sqrt{L}$, τ, $\bar{\beta}$ perform the following:

1. Obtain values of $(V/\sqrt{L})_m$ from Fig. 8
2. Obtain values of $(R_{AW}/wb^3)_m$ from Fig. 8
3. Calculate $V/\sqrt{L}/(V/\sqrt{L})_m$
4. Obtain $R_{AW}/(R_{AW})_m$ from Fig. 9
5. Multiply Lines 2x4 to get R_{AW}/wb^3
6. E corrections - Eqs. (1)-(3)
7. Multiply Lines 5x6 - Final values
8. Interpolate for given $H_{1/3}/b$

B. Repeat procedure for other speeds

Line	$H_{1/3}/\bar{b}$		
	.2	.4	.6
1	3.6	3.6	3.6
2	.0235	.040	.047
3	1.11	1.11	1.11
4	.96	.96	.96
5	.0226	.0384	.0451
6*	1.025	1.051	1.076
7	.0232	.0404	.0486

*It will be necessary to plot E vs. $V/\sqrt{L}$ and interpolate for given speed.

WORK SHEET (continued)

IV. HEAVE AND PITCH MOTIONS

A. At given $H_{1/3}/\bar{b}$ obtain 1/10 highest values at $\tau = 4^{o}$, $\beta = 20^{o}$

1. Obtain heave or pitch from
2. Figs 10-14
3. Interpolate for correct $L/\bar{b}$
4. F. - Trim correction, Eq (4)
5. G. - Deadrise correction, Eq. (5)
6. Final values - multiply lines 3x4x5
7. Interpolate for given speed

B. Repeat procedure for other $H_{1/3}/b$

Line	$L/\bar{b}$		Heave $V/\sqrt{L}$ 4	Pitch $V/\sqrt{L}$ 4
1.	4		.155	4.0
2.	5		.170	4.0
3.	$L/\bar{b}$=	4.6	.164	4.0
4.			1.18	1.18
5.			1	1
6.			.194	4.7^{o}

V. ACCELERATIONS

A. At given $H_{1/3}/b$ obtain avg cg and bow accelerations at $\tau = 4^{o}$ and $\beta = 20^{o}$

1. & 2. Obtain η_{cg} from Figs 15-17
3. Interpolate for correct $L/\bar{b}$
4. Obtain η_{bow} from Figs 18-21
5.
6. Interpolate for correct $L/\bar{b}$
7. Trim-Deadrise Correction, Eq. (6)
8. Multiply Lines 3x7 for η_{cg}
9. Multiply Lines 6x7 for η_{bow}
10. Bow warp = .85 η_{bow}
11. Interpolate for given speed

B. Repeat procedure for other $H_{1/3}/b$

Line	$L/\bar{b}$	$V/\sqrt{L}$ 2	$V/\sqrt{L}$ 4	$V/\sqrt{L}$ 6
1	4		.30	
2	5		.56	
3	$L/\bar{b}$		.44	
4	4		.95	
5	5		1.90	
6	$L/\bar{b}$		1.40	
7			1.38	
8			.61	
9			1.93	
10*			1.64	

*May vary with bow shape

DISCUSSION

The working design charts with the correction factors form the real basis of this report. Not only are they useful for making full scale predictions on actual boats, but they show some of the more significant trends of the hull parameters on planing hull performance. Some of these trends will be summarized in this section; as well as a general overall view will be given of the planing hull behavior which may not be obvious from the charts.

Effect of Speed

The three speed-length ratios tested represent three distinct flow regimes which a planing hull may operate in. At a speed-length ratio of $2(C_V = 1.2$ to $1.3)$, the planing hull behaves much like a displacement ship. This is a "pre-hump" condition, with the buoyant forces playing the major role. Some lift is generated, and the flow breaks clean of the transom, but there is a significant amount of side-wetting. Added resistance in waves and acceleration levels are relatively low, while pitch motions are large. The heave and pitch motions oscillate about mean levels which are identical to the running values obtained in smooth water. The motion distributions about the mean were only slightly different from the Rayleigh, with $\dot{r}$ values generally less than 0.1.

At a speed-length ratio of $4(C_V = 2.4 - 2.7)$, the hull is planing, with some side-wetting still prevalent. Perhaps the majority of pleasure and utility craft operate closer to this "post hump" condition than at either the speed-length ratios of 2 or 6. Dynamic and buoyant forces are both significant at this speed. In waves, the mean heave and trim were generally close to their smooth water values. The motion distributions again were close to Rayleigh $(r < 0.1)$ with generally higher r values $(.05 - .15)$ for the $\tau = 6^{\circ}$ configurations. Added resistance is a maximum at or near this speed-length ratio.

For the highest speed ($V/\sqrt{L} = 6$), the planing hull is fully planing ($C_v = 3.6 - 4.0$), buoyancy plays only a minor role, and no side-wetting was observed. Few boats except for high performance hulls, such as ocean racers, can maintain operation in rough water at this condition. The planing boat moves across the tops of the waves for the most part, but rebounds violently in the higher and longer waves. Excessive spray and high accelerations are also associated with performance at this speed-length ratio. Significant shifts in the mean heave and trim levels were observed in the highest sea states. Except for the minimum heave motions (with r values less than 0.07), the heave and pitch excursions departed substantially from the pure Rayleigh distribution. r values as high as 0.27 were recorded in the medium sea state ($H_{1/3}/b = 0.444$). Because of the excessive accelerations and motions experienced by the hull in large waves, the largest sea state ($H_{1/3}/b = .667$) was not considered as a test condition.

Overall, as the planing hull traverses these speed regimes, it goes from a contouring type of behavior to that of platforming. This means that at low speed the boat tends to follow the wave profile while at high speed, it skips from crest-to-crest ignoring the small waves and responding only to waves of large height and long length. As a result the average amplitude of the motions goes down with speed, but the 1/10 highest motions generally increase. This behavior is also substantiated by the Phase I[1] tests, where the response curves indicated a sharp tuning and greater magnification near resonance as the speed was increased. On this basis, the motions in irregular seas as a function of speed compare quite well with the trends predicted from Phase I. Acceleration levels build up considerably with speed to such an extent that at speed-length ratios of 5 or 6 in large sea states, operation is impractical not only from a human standpoint, but also because the hull structure would collapse.

Effect of Significant Wave Height

It is generally accepted and found herein that all performance indicators deteriorate in rough water. Resistance, motions, and accelerations all increase with greater wave severity. Naturally for different

sea spectra, as the significant height of the waves increase, the period of maximum energy shifts toward the longer periods and consequently longer wave lengths. This also means that more wave energy will appear at the planing hull's natural periods which were found in Phase I to be in a wave length range of three to four hull lengths. Thus one would expect the motions to increase significantly with greater wave height.

Effect of Deadrise

The deadrise effect on planing hull behavior is significant and very much a function of speed. In fact this hull parameter generally becomes of more importance as the speed increases. Its single disadvantage is the greater horsepower needed to drive the deeper deadrise hulls through smooth water. In rough water however, deadrise has little effect on the added resistance at $V/\sqrt{L} = 2$. At the higher speeds of $V/\sqrt{L} = 4$ and 6, the added increment due to waves actually decreases. Thus, once a designer has installed enough "smooth water horsepower," the percentage increase in horsepower for the deep V hulls to maintain speed in waves is not that much greater.

The motions are independent of deadrise at speed-length ratios of 2 and 4. It is only at the high speeds ($V/\sqrt{L} > 4$) where deadrise accounts for substantial attenuation of the motions.

It is on the acceleration levels where deadrise has perhaps its greatest advantage. Both the bow and C.G. acceleration decrease linearly with deadrise, so that a 50% reduction can be realized between a 10° and 30° deadrise hull.

These results in irregular waves are qualitatively identical to that found in Phase I in regular waves.

Effect of Trim

Trim is an equally important parameter, and like deadrise, it becomes more significant with higher speeds. Motions in particular increase with higher trim angles. A two degree increase in running trim from 4° to

6° accounts for a 17% increase in motions at $V/\sqrt{L} = 2$ and a 33% increase at $V/\sqrt{L} = 4$. Accelerations build up in direct proportion to the trim over the range of 3° to 7°. Added resistance due to trim increase is greater at $V/\sqrt{L} = 2$ but less at $V/\sqrt{L} = 4$ and 6. This is primarily due to the hump speed shifting to lower values with higher trims. These trends correlate well with those found in regular waves (Phase I).

Effect of Load and Length-Beam Ratio

The effects of load and length-beam ratio must be discussed together since they are integrally related. During the tests, when changing load at a given length-beam ratio, the inertia was kept constant (i.e. load was concentrated at the C.G.). Also the gyradius was maintained at 25% of the length for a constant $C_{\Delta}/L/b = 0.12$. This meant the inertia varied as the length cubed. All other parameters remained the same.

Using this test technique for load variations, acceleration levels increased significantly with decreasing load and higher length-beam ratio at all speeds. Motions were independent of load at $V/\sqrt{L} = 2$, but decreased with load at the higher speeds. Greater length-beam ratios attenuated the motions at $V/\sqrt{L} = 2$; but magnified them at $V/\sqrt{L} = 4$ and 6. In the smaller sea states ($H_{1/3}/b \leq .2$), motions were not a function of the length. Added resistance varies differently with load and length-beam ratio according to the speed (see correction factors). At speed-length ratios of 2, 4, and 6; L/b, $C_{\Delta}/L/b$, and C_{Δ} are the controlling parameters respectively affecting the <u>added</u> resistance.

Effect of Bow Shape

The effect of warping the bow had surprisingly little effect on the overall performance of the planing hull. At speed-length ratios of 2 and 6, the added resistance was reduced only slightly, the motions were virtually the same, and accelerations at the bow were decreased on the order of 15%. At $V/\sqrt{L} = 4$, the results are rather inconclusive due to a significant change in the mean running trim. The altered bow needed spray rails at this speed to cure a diving problem in smooth water. This tendency may still be present somewhat in rough water.

CONCLUSIONS

A series of constant-deadrise models of varying length and a single model with a conventional type (warped) bow were tested in irregular waves (Pierson-Moskowitz spectra) and the effects of deadrise, trim, load, length-beam ratio, bow form, speed and significant wave height were investigated on the performance. Evaluation was based on added resistance, heave and pitch motions, and bow and C.G. accelerations. Care was taken, in changing a single parameter from one value to another, to keep other model parameters the same.

The data was successfully analyzed by statistically describing the distribution of the motions and accelerations. The accumulated frequency distributions (probability) for the motions were shown to follow a "distorted Rayleigh" function; while the peak accelerations were distributed according to a simple exponential function. Differences between configurations could therefore be made on the basis of some distribution parameters, which for the motions was taken to be the 1/10 highest probability levels, and for the accelerations, the average peak value.

The results of the parametric evaluation were summarized in design charts which will enable those interested in planing hulls to make full scale performance predictions on actual boats. A number of worked examples indicate that good estimates can be made of the added resistance, motions and accelerations.

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TABLE I

MODEL CONFIGURATIONS

Symbol	L/b	β	C_Δ	k_1	LCG	τ	k	$V/\sqrt{L}$	d/b	τ_o	R/Δ
A	5	10	0.600	0.120	62.0	4	24.8	2	-.011	1.3	0.113
B	"	"	"	"	59.3	"	24.7	4	0.069	0.8	0.143
C	"	"	"	"	68.0	"	25.0	6	0.159	2.9	0.155
D	"	30	"	"	66.7	6	24.7	4	0.091	2.8	0.179
E	"	"	"	"	62.2	4	25.0	2	-.012	1.7	0.114
F	"	"	"	"	60.4	"	25.0	4	0.058	1.2	0.179
G	"	"	"	"	62.1	"	25.0	6	0.116	1.6	0.256
H	"	10	"	"	67.0	6	24.8	4	0.128	2.6	0.132
I	"	20	"	"	59.2	4	24.9	4	0.060	0.9	0.145
J	"	"	0.720	0.144	59.4	"	22.8	2	-.018	1.1	0.119
K	"	"	0.600	0.120	61.6	"	24.9	2	-.013	1.4	0.110
L	"	"	0.480	0.096	62.8	"	27.6	4	0.060	1.3	0.147
M	"	"	0.600	0.120	64.0	"	24.8	6	0.126	2.0	0.198
N	"	"	0.480	0.096	64.7	"	27.7	2	-.010	1.7	0.101
O	"	"	0.600	0.120	66.8	6	25.0	4	0.103	2.7	0.146
P	"	"	"	"	67.7	"	25.1	2	-.009	3.0	0.118
Q	"	"	0.720	0.144	56.5	4	22.6	4	0.067	0.4	0.168
R	"	"	"	"	57.6	"	22.9	6	0.128	0.6	0.201
S	4	"	0.480	0.120	54.3	"	24.9	4	0.062	-0.6	0.192
T	"	"	0.384	0.096	57.7	"	27.6	4	0.059	0.2	0.147
U	"	"	0.480	0.120	57.7	"	24.8	6	0.118	0.3	0.194
V	"	"	"	"	58.8	"	24.7	2	-.018	0.6	0.133
W	"	"	0.384	0.096	61.4	"	27.8	2	-.012	1.0	0.123
X	"	"	"	"	65.0	"	27.5	6	0.121	2.0	0.210
Warped Bow											
AA	4	20	0.480	0.120	59.7	4	25.0	6	0.129	0.5	0.202
BB	"	"	"	"	59.7	"	25.0	2	-.022	0.5	0.132
CC	"	"	"	"	55.2	"	24.7	4	0.070	-1.1	0.170

Table II

RESISTANCE IN WAVES

Condition	Symbol	$\bar{V}/\sqrt{L}$	$H_{1/3}/b$	R_W/Δ	R_{AW}/Δ	R_{AW}/wb^3
			Constant Thrust			
-	A	2.03	0.444	0.132	0.019	0.011
-	A	2.04	0.667	0.137	0.024	0.014
			Constant Speed			
1	A	2.00	0.667	0.138	0.025	0.015
2	A	1.99	0.444	0.136	0.023	0.014
3	B	3.96	0.222	0.189	0.046	0.028
4	B	4.00	0.444	0.219	0.076	0.046
5	B	3.97	0.667	0.225	0.082	0.049
6	C	5.98	0.222	0.205	0.050	0.030
7	C	6.00	0.444	0.221	0.066	0.040
8	D	4.01	0.444	0.212	0.033	0.020
9	D	4.02	0.222	0.191	0.012	0.007
10	D	4.05	0.667	0.218	0.039	0.023
11	E	2.01	0.667	0.146	0.032	0.019
12	E	1.98	0.444	0.137	0.023	0.014
13	F	4.00	0.444	0.239	0.060	0.036
14	F	3.99	0.222	0.207	0.028	0.017
15	F	4.00	0.667	0.248	0.069	0.041
16	G	6.02	0.222	0.284	0.028	0.017
17	G	6.01	0.444	0.310	0.054	0.032
18	H	3.99	0.444	0.188	0.056	0.034
19	H	4.03	0.222	0.169	0.037	0.022
20	H	4.00	0.667	0.202	0.070	0.042
21	I	4.00	0.444	0.219	0.074	0.044
22	I	4.02	0.222	0.194	0.049	0.029
23	I	3.99	0.667	0.235	0.090	0.054
24	J	1.95	0.444	0.132	0.013	0.009
25	K	1.97	0.444	0.132	0.022	0.013
26	K	1.98	0.667	0.139	0.029	0.017
27	K	1.98	0.222	0.131	0.021	0.013
28	L	3.96	0.222	0.192	0.045	0.022
29	L	3.95	0.667	0.232	0.085	0.041
30	M	5.97	0.444	0.251	0.053	0.032
31	M	5.99	0.222	0.233	0.035	0.021
32	N	1.98	0.444	0.132	0.031	0.015
33	N	1.99	0.222	0.127	0.026	0.012
34	O	3.98	0.222	0.177	0.031	0.019
35	O	4.02	0.444	0.205	0.059	0.035
36	O	4.00	0.667	0.210	0.064	0.038
37	P	1.97	0.667	0.160	0.042	0.025
38	P	1.97	0.444	0.154	0.036	0.022
39	P	2.02	0.222	0.148	0.030	0.018

TABLE II (continued)

Condition	Symbol	$\tilde{V}/\sqrt{L}$	$H_{1/3}/b$	R_W/Δ	R_{AW}/Δ	R_{AW}/wb^3
			Constant Speed			
40	Q	3.99	0.222	0.203	0.035	0.025
41	Q	4.01	0.444	0.236	0.068	0.049
42	Q	4.01	0.667	0.248	0.080	0.058
43	R	6.00	0.444	0.278	0.077	0.055
44	R	5.98	0.222	0.238	0.037	0.027
45	S	3.98	0.222	0.239	0.047	0.023
46	S	4.01	0.444	0.268	0.076	0.036
47	S	4.00	0.667	0.277	0.085	0.041
48	T	3.98	0.667	0.242	0.095	0.037
49	T	4.00	0.444	0.237	0.090	0.035
50	T	3.99	0.222	0.216	0.069	0.027
51	U	5.97	0.222	0.251	0.057	0.027
52	U	6.00	0.444	0.287	0.093	0.045
53	V	1.98	0.222	0.148	0.015	0.007
54	V	2.01	0.444	0.154	0.021	0.010
55	V	2.02	0.677	0.157	0.024	0.012
56	W	2.00	0.667	0.148	0.025	0.010
57	W	2.00	0.444	0.143	0.020	0.008
58	X	6.00	0.444	0.269	0.059	0.023
59	X	6.00	0.222	0.254	0.044	0.017
60	AA	6.00	0.222	0.251	0.049	0.024
61	AA	6.01	0.444	0.272	0.070	0.034
62	BB	1.98	0.444	0.139	0.007	0.003
63	BB	1.98	0.667	0.148	0.016	0.008
64	CC	3.99	0.667	0.291	0.121	0.058
65	CC	3.99	0.444	0.271	0.101	0.048

TABLE III

HEAVE MOTIONS

Condition	Symbol	$h_{d.c.}/b$	$\bar{h}/b$	CRESTS r	CRESTS h_{50}/b	CRESTS h_{90}/b	TROUGHS r	TROUGHS h_{50}/b	TROUGHS h_{90}/b
-	A	-.018	0.115	.052	0.111	0.216	.052	0.111	0.216
-	A	-.009	0.165	.109	0.162	0.342	.044	0.159	0.304
1	A	-.003	0.161	.095	0.156	0.323	.019	0.152	0.283
2	A	0	0.118	.052	0.113	0.219	.017	0.111	0.206
3	B	0.063	0.037	.081	0.036	0.074	.020	0.034	0.064
4	B	0.080	0.105	.161	0.104	0.243	.086	0.103	0.210
5	B	0.081	0.164	.109	0.161	0.341	.054	0.159	0.307
6	C	0.164	0.038	.179	0.038	0.091	.063	0.037	0.072
7	C	0.168	0.137	.272	0.135	0.424	.062	0.132	0.259
8	D	0.117	0.132	.189	0.130	0.323	.047	0.127	0.243
9	D	0.103	0.040	.174	0.039	0.094	.028	0.038	0.071
10	D	0.134	0.192	.171	0.191	0.453	.079	0.187	0.376
11	E	-.002	0.171	.098	0.167	0.346	.056	0.165	0.321
12	E	-.009	0.113	.056	0.109	0.213	.032	0.109	0.204
13	F	0.064	0.117	.119	0.114	0.248	.073	0.113	0.226
14	F	0.054	0.031	.148	0.031	0.071	.028	0.030	0.057
15	F	0.071	0.178	.090	0.173	0.355	.045	0.171	0.328
16	G	0.117	0.028	.126	0.028	0.060	.058	0.027	0.052
17	G	0.130	0.123	.121	0.120	0.261	.044	0.118	0.226
18	H	0.124	0.128	.183	0.127	0.310	.048	0.123	0.237
19	H	0.132	0.040	.146	0.039	0.088	.018	0.038	0.060
20	H	0.143	0.191	.149	0.187	0.430	.023	0.182	0.340
21	I	0.074	0.108	.129	0.105	0.232	.079	0.104	0.211
22	I	0.074	0.034	.100	0.033	0.069	.040	0.032	0.062
23	I	0.080	0.167	.118	0.162	0.350	.059	0.160	0.313
24	J	-.017	0.105	.077	0.102	0.205	.051	0.101	0.196
25	K	-.010	0.109	.051	0.104	0.202	.038	0.104	0.198
26	K	-.007	0.159	.082	0.154	0.313	.118	0.155	0.335
27	K	-.013	0.042	.050	0.040	0.078	.010	0.039	0.072
28	L	0.071	0.039	.071	0.038	0.076	.029	0.037	0.070
29	L	0.103	0.168	.184	0.167	0.418	.061	0.162	0.319
30	M	0.169	0.147	.222	0.145	0.393	.033	0.140	0.265
31	M	0.140	0.036	.114	0.036	0.076	.048	0.034	0.067
32	N	0.007	0.110	.061	0.105	0.208	.085	0.107	0.217
33	N	-.002	0.044	.031	0.041	0.077	0	0.040	0.073
34	O	0.107	0.039	.152	0.038	0.087	.029	0.037	0.069
35	O	0.144	0.160	.170	0.158	0.376	.018	0.151	0.281
36	O	0.152	0.203	.140	0.199	0.447	.084	0.197	0.402
37	P	0.017	0.172	.119	0.169	0.363	.073	0.167	0.334
38	P	-.016	0.114	.048	0.110	0.211	.048	0.110	0.211
39	P	-.007	0.046	.070	0.044	0.088	.030	0.043	0.082
40	Q	0.059	0.030	.063	0.029	0.056	.031	0.028	0.053
41	Q	0.062	0.100	.058	0.095	0.188	.093	0.097	0.200
42	Q	0.063	0.138	.119	0.135	0.291	.110	0.134	0.286

TABLE III (continued)

Condition	Symbol	$h_{d.c.}/b$	$\bar{h}/b$	CRESTS r	CRESTS h_{50}/b	CRESTS h_{90}/b	TROUGHS r	TROUGHS h_{50}/b	TROUGHS h_{90}/b
43	R	0.135	0.099	.242	0.099	0.281	.053	0.096	0.185
44	R	0.134	0.030	.146	0.029	0.066	.042	0.029	0.054
45	S	0.069	0.040	.086	0.039	0.079	.054	0.038	0.074
46	S	0.066	0.107	.144	0.105	0.238	.087	0.104	0.212
47	S	0.052	0.158	.122	0.155	0.335	.078	0.152	0.308
48	T	0.069	0.159	.143	0.156	0.351	.050	0.152	0.296
49	T	0.063	0.111	.162	0.109	0.256	.048	0.107	0.204
50	T	0.061	0.050	.119	0.049	0.105	.012	0.047	0.087
51	U	0.119	0.044	.140	0.043	0.098	.037	0.042	0.080
52	U	0.150	0.127	.242	0.126	0.358	.040	0.121	0.231
53	V	-.017	0.057	.038	0.054	0.103	.038	0.054	0.103
54	V	-.012	0.117	.085	0.113	0.230	.054	0.112	0.218
55	V	-.016	0.163	.063	0.157	0.310	.114	0.159	0.340
56	W	0.001	0.163	.170	0.161	0.384	.068	0.158	0.312
57	W	-.003	0.121	.047	0.116	0.222	.062	0.117	0.229
58	X	0.183	0.151	.232	0.149	0.413	.049	0.144	0.279
59	X	0.144	0.059	.141	0.058	0.131	.026	0.057	0.106
Warped Bow									
60	AA	0.144	0.052	.084	0.051	0.103	.048	0.050	0.096
61	AA	0.157	0.129	.125	0.127	0.276	.050	0.124	0.240
62	BB	-.012	0.123	.128	0.121	0.264	.011	0.117	0.214
63	BB	-.011	0.163	.102	0.159	0.334	.091	0.159	0.327
64	CC	0.050	0.170	.068	0.165	0.325	.068	0.164	0.326
65	CC	0.056	0.113	.058	0.109	0.213	.116	0.111	0.238

TABLE IV

PITCH MOTIONS

Condition	Symbol	$\theta_{d.c.}$	$\bar{\theta}$	CRESTS r	CRESTS θ_{50}	CRESTS θ_{90}	TROUGHS r	TROUGHS θ_{50}	TROUGHS θ_{90}
-	A	3.77	2.76	.067	2.67	5.28	.042	2.64	5.06
-	A	3.87	3.20	.081	3.10	6.27	.098	3.11	6.47
1	A	3.93	3.63	.022	3.45	6.44	.037	3.47	6.60
2	A	3.98	2.81	.061	2.72	5.33	.034	2.69	5.09
3	B	3.56	1.25	.043	1.20	2.29	.060	1.20	2.36
4	B	3.35	2.29	.042	2.19	4.19	.104	2.23	4.69
5	B	3.32	2.97	.061	2.87	5.63	.104	2.90	6.09
6	C	3.86	1.10	.154	1.08	2.48	.103	1.07	2.24
7	C	4.74	2.42	.177	2.39	5.78	.094	2.36	4.87
8	D	6.16	3.06	.051	2.94	5.69	.068	2.96	5.86
9	D	6.03	1.19	.129	1.16	2.56	.048	1.14	2.20
10	D	6.29	3.74	.084	3.64	7.40	.084	3.64	7.40
11	E	4.32	3.98	.066	3.85	7.61	.060	3.84	7.53
12	E	3.93	2.90	.060	2.80	5.49	.087	2.82	5.76
13	F	3.68	2.36	.039	2.26	4.30	.087	2.29	4.67
14	F	3.77	0.99	.050	0.95	1.83	.033	0.94	1.78
15	F	3.51	2.97	.098	2.89	6.01	.054	2.86	5.55
16	G	3.45	0.69	.078	0.67	1.36	.127	0.68	1.49
17	G	3.73	1.79	.143	1.76	3.98	.134	1.76	3.91
18	H	5.39	3.14	.071	3.04	6.06	.053	3.03	5.87
19	H	5.58	1.28	.138	1.26	2.81	.085	1.24	2.53
20	H	5.56	3.76	.086	3.65	7.45	.086	3.65	7.45
21	I	3.77	2.46	.060	2.37	4.66	.043	2.36	4.52
22	I	3.94	1.19	.054	1.14	2.23	.036	1.14	2.16
23	I	3.63	3.07	.077	2.98	5.98	.067	2.97	5.88
24	J	3.59	2.70	.058	2.61	5.09	.029	2.58	4.85
25	K	3.88	2.90	.053	2.79	5.42	.032	2.77	5.23
26	K	3.89	3.72	.092	3.62	7.44	.046	3.57	6.85
27	K	3.73	1.64	.054	1.57	3.06	.018	1.55	2.88
28	L	3.89	1.16	.091	1.12	2.31	.039	1.11	2.11
29	L	3.96	3.24	.047	3.12	6.00	.047	3.12	6.00
30	M	4.46	2.28	.182	2.25	5.51	.064	2.20	4.34
31	M	4.06	0.91	.168	0.90	2.13	.080	0.88	1.78
32	N	4.13	3.08	.044	2.96	5.67	.022	2.93	5.47
33	N	4.09	1.68	.027	1.60	3.01	.018	1.59	2.96
34	O	6.08	1.32	.104	1.29	2.70	.052	1.27	2.46
35	O	6.05	3.34	.113	3.26	6.96	.053	3.21	6.23
36	O	6.13	4.02	.101	3.92	8.18	.050	3.86	7.47
37	P	6.72	4.39	.092	4.27	8.79	.031	4.18	7.89
38	P	6.57	3.46	.021	3.29	6.13	.085	3.36	6.85
39	P	6.45	1.87	.054	1.79	3.49	.036	1.78	3.38
40	Q	3.86	1.04	.035	0.99	1.88	.071	1.01	2.00
41	Q	3.69	2.26	.054	2.18	4.23	.100	2.20	4.60
42	Q	3.58	2.63	.046	2.52	4.85	.146	2.58	5.85

TABLE IV (continued)

Condition	Symbol	$\theta_{d.c.}$	$\bar{\theta}$	CRESTS			TROUGHS		
				r	θ_{50}	θ_{90}	r	θ_{50}	θ_{90}
43	R	3.86	1.46	.212	1.45	3.81	.174	1.44	3.47
44	R	3.74	0.56	.221	0.56	1.50	.234	0.56	1.55
45	S	3.66	1.35	.063	1.31	2.57	.126	1.32	2.89
46	S	3.86	2.72	.050	2.61	5.05	.076	2.63	5.28
47	S	3.56	3.15	.055	3.04	5.91	.117	3.08	6.63
48	T	3.63	3.27	.068	3.16	6.27	.095	3.18	6.60
49	T	3.75	2.69	.056	2.59	5.04	.080	2.61	5.26
50	T	3.77	1.70	.040	1.63	3.11	.080	1.65	3.34
51	U	3.91	1.27	.111	1.24	2.64	.043	1.22	2.34
52	U	4.29	2.46	.134	2.42	5.36	.097	2.40	4.98
53	V	3.91	2.24	.033	2.13	4.04	.044	2.14	4.11
54	V	3.88	3.21	.079	3.12	6.28	.020	3.05	5.68
55	V	4.05	3.87	.043	3.71	7.11	.064	3.74	7.37
56	W	4.16	3.83	.067	3.70	7.32	.047	3.67	7.07
57	W	4.12	3.33	.051	3.20	6.19	.057	3.21	6.26
58	X	5.06	2.69	.170	2.66	6.34	.091	2.62	5.39
59	X	4.21	1.72	.100	1.68	3.50	.050	1.65	3.20
				Warped Bow					
60	AA	3.93	1.46	.096	1.42	2.95	.043	1.40	2.68
61	AA	4.18	2.50	.107	2.44	5.17	.064	2.42	4.77
62	BB	3.88	3.25	.054	3.13	6.10	.054	3.13	6.10
63	BB	4.22	3.80	.072	3.68	7.34	.099	3.70	7.71
64	CC	2.61	3.34	.054	3.21	6.24	.129	3.27	7.18
65	CC	2.84	2.59	.066	2.50	4.95	.123	2.54	5.51

TABLE V

ACCELERATIONS

Condition	Symbol	$\bar{\eta}_{bow}$	$\bar{\eta}_{cg}$
1	A	2.18	0.53
2	A	1.44	0.33
3	B	2.06	0.67
4	B	3.44	1.04
5	B	4.26	1.47
6	C	3.56	1.01
7	C	7.20	2.40
8	D	3.06	0.73
9	D	1.40	0.34
10	D	3.73	1.01
11	E	1.35	0.24
12	E	0.83	0.15
13	F	1.80	0.39
14	F	1.06	0.24
15	F	2.39	0.66
16	G	1.36	0.36
17	G	3.05	1.00
18	H	5.57	1.70
19	H	3.02	0.90
20	H	6.31	1.91
21	I	2.35	0.71
22	I	1.65	0.45
23	I	3.09	1.05
24	J	0.79	0.15
25	K	1.17	0.26
26	K	1.78	0.43
27	K	0.82	0.14
28	L	2.10	0.55
29	L	4.20	1.19
30	M	5.33	1.77
31	M	2.10	0.68
32	N	1.55	0.31
33	N	1.09	0.19
34	O	2.09	0.57
35	O	4.00	1.22
36	O	5.50	1.68
37	P	3.12	0.65
38	P	1.97	0.38
39	P	1.30	0.22
40	Q	1.17	0.34
41	Q	1.73	0.43
42	Q	2.01	0.59
43	R	3.36	1.36
44	R	1.72	0.58
45	S	1.06	0.29
46	S	1.93	0.62
47	S	2.18	0.68
48	T	2.89	0.99
49	T	2.26	0.85
50	T	1.91	0.57
51	U	2.35	0.83
52	U	4.08	1.88
53	V	0.56	0.13
54	V	0.66	0.15
55	V	0.80	0.30
56	W	1.22	0.39
57	W	1.06	0.30
58	X	5.03	1:81
59	X	3.02	0.95
	Warped Bow		
60	AA	1.98	0.69
61	AA	3.40	1.49
62	BB	0.62	0.17
63	BB	0.66	0.25
64	CC	1.34	0.52
65	CC	1.04	0.35

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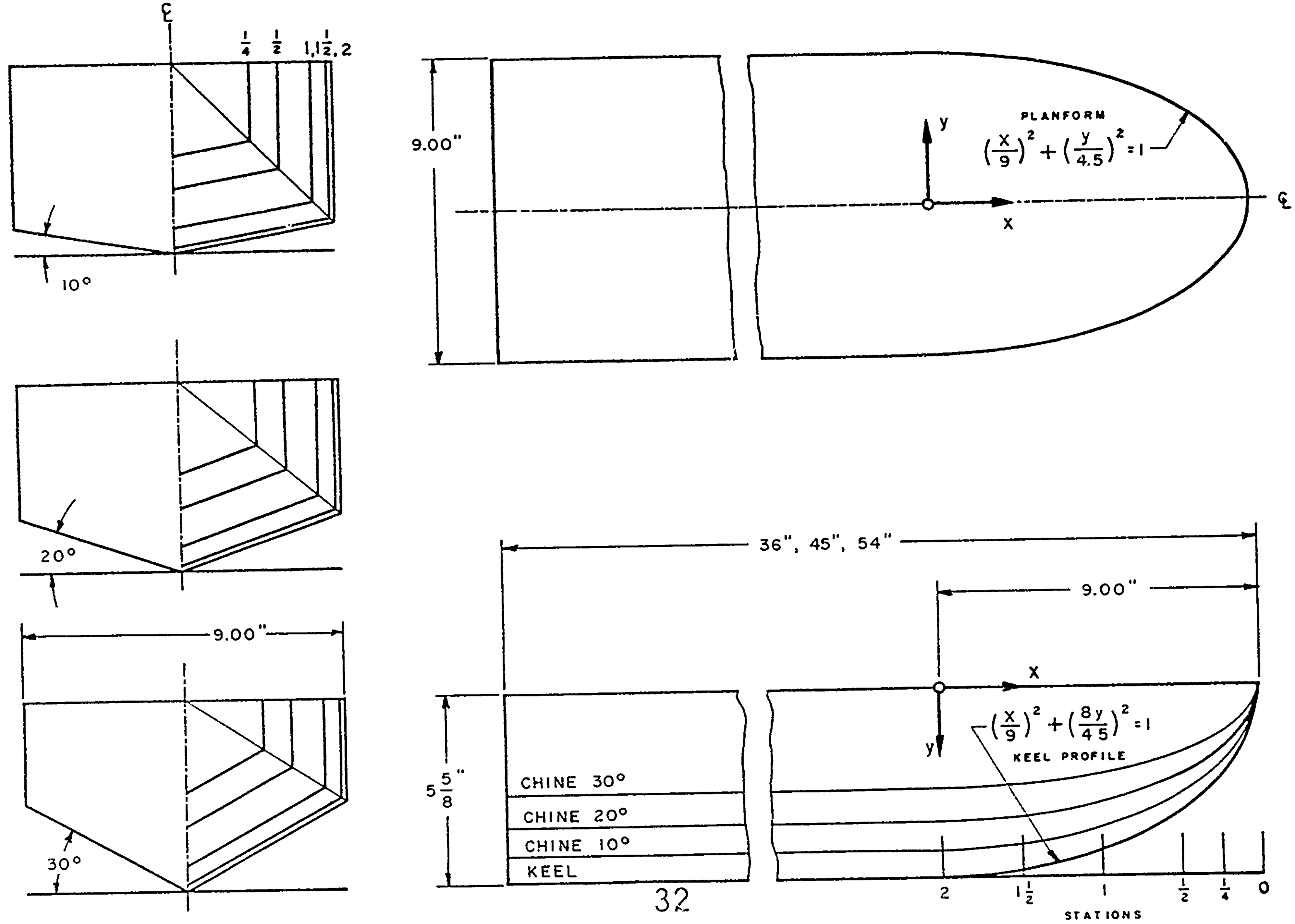


FIG. 1. LINES OF PRISMATIC MODELS

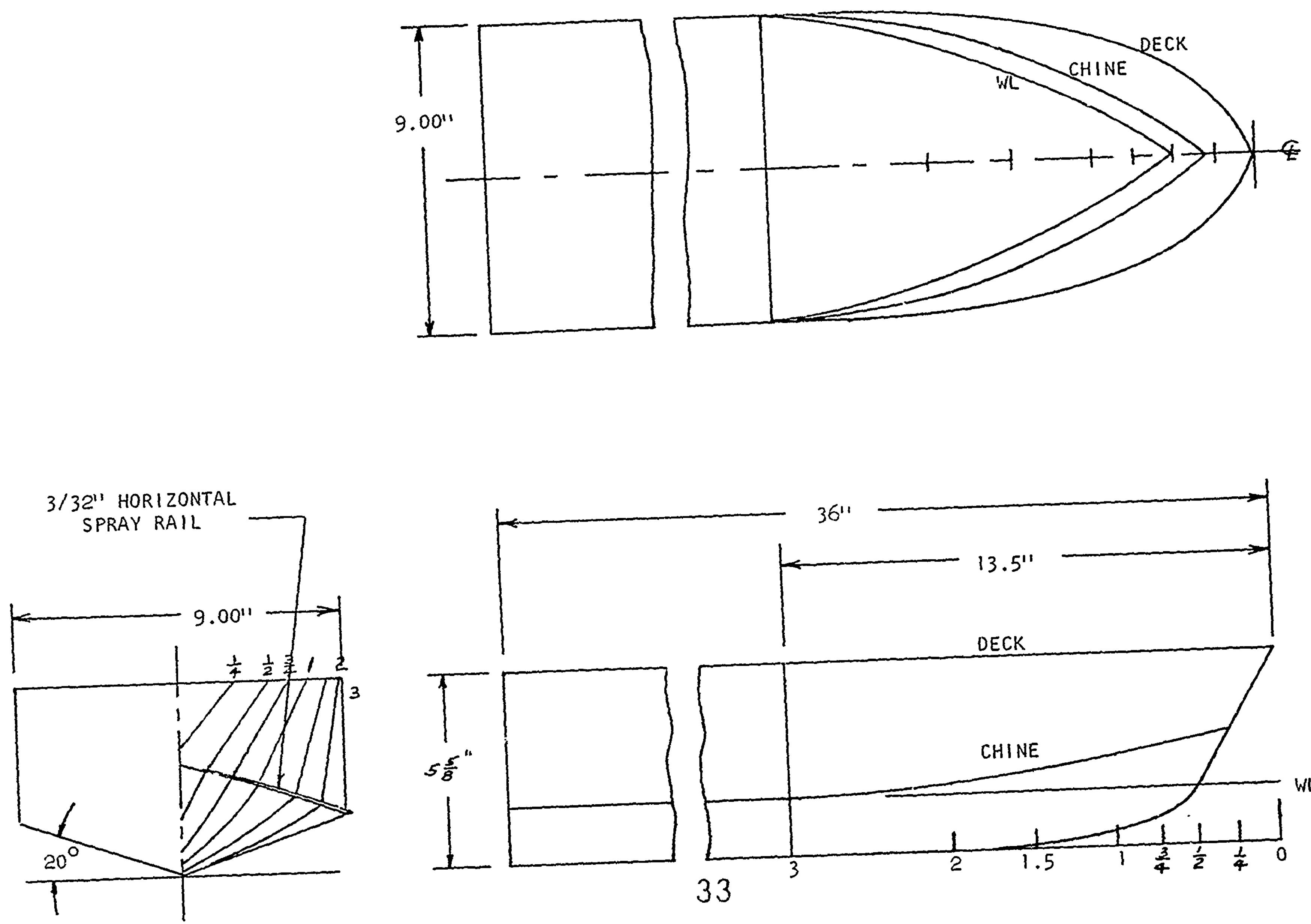
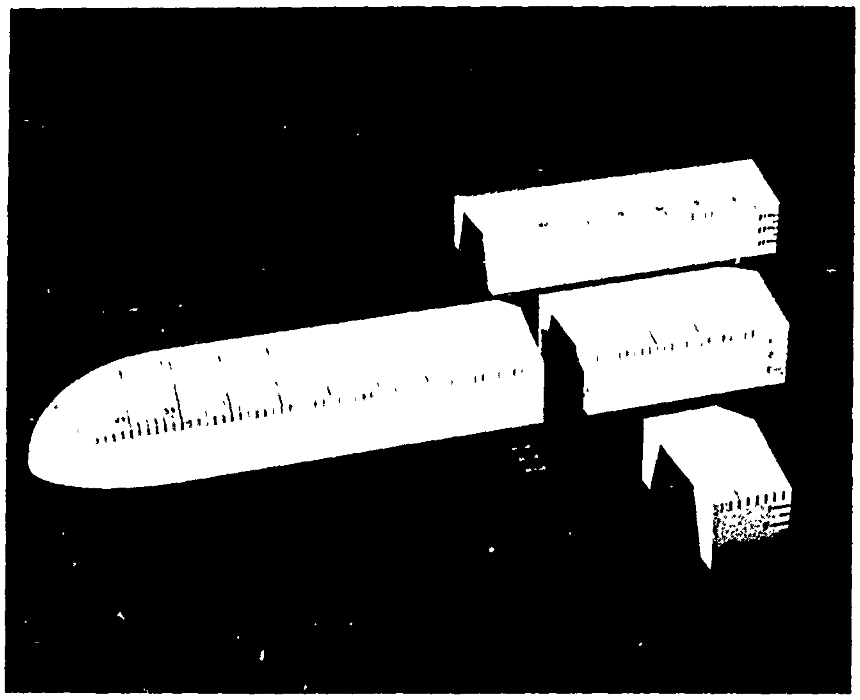
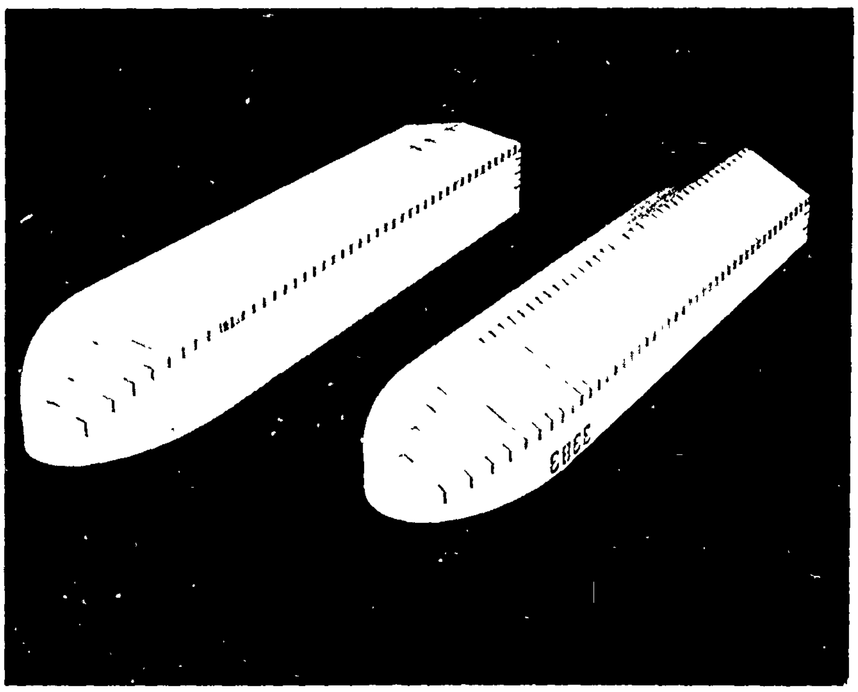


FIG. 2 LINES OF PRISMATIC MODEL WITH CONVENTIONAL BOW



20° DEADRISE MODELS



10° AND 30° DEADRISE MODELS

FIG. 3 PHOTOGRAPHS OF TEST MODELS

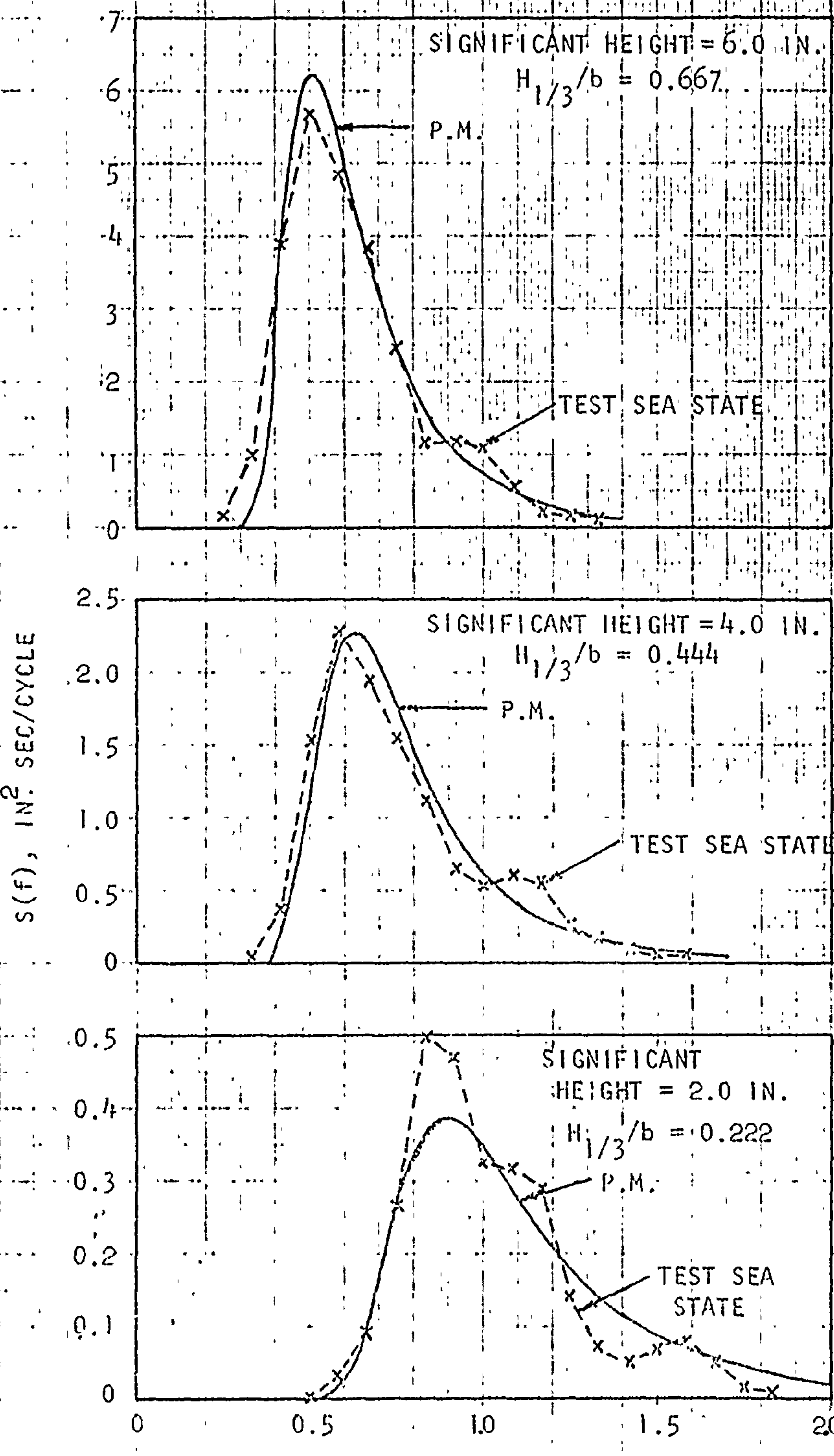


FIG. 4 COMPARISON OF MODEL TO PIERSON-MOSKOWITZ SEA SPECTRA

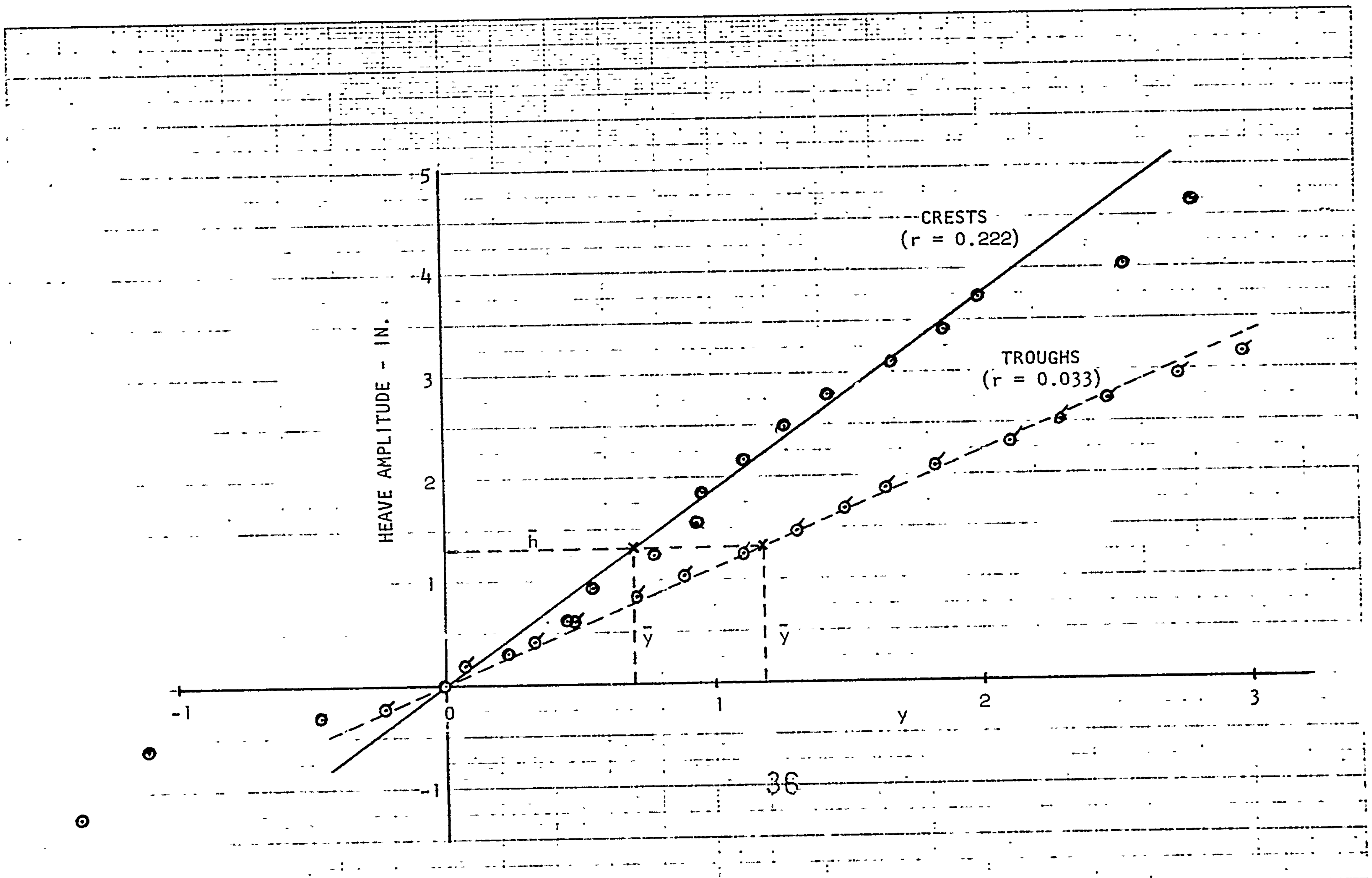


FIG. 5 TYPICAL HEAVE MOTION DISTRIBUTION - CONDITION 30

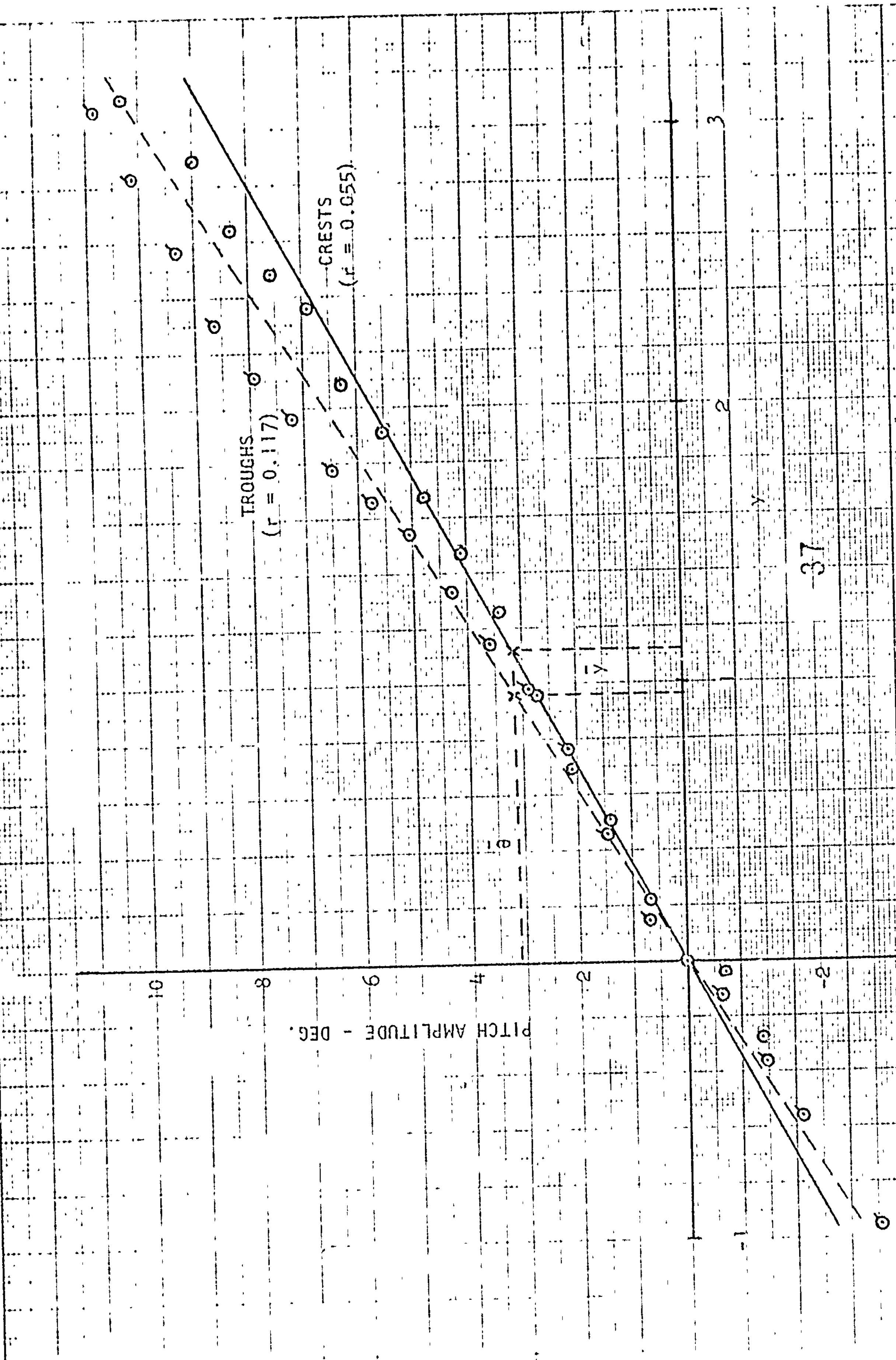


FIG. 6 TYPICAL PITCH MOTION DISTRIBUTION - CONDITION 47

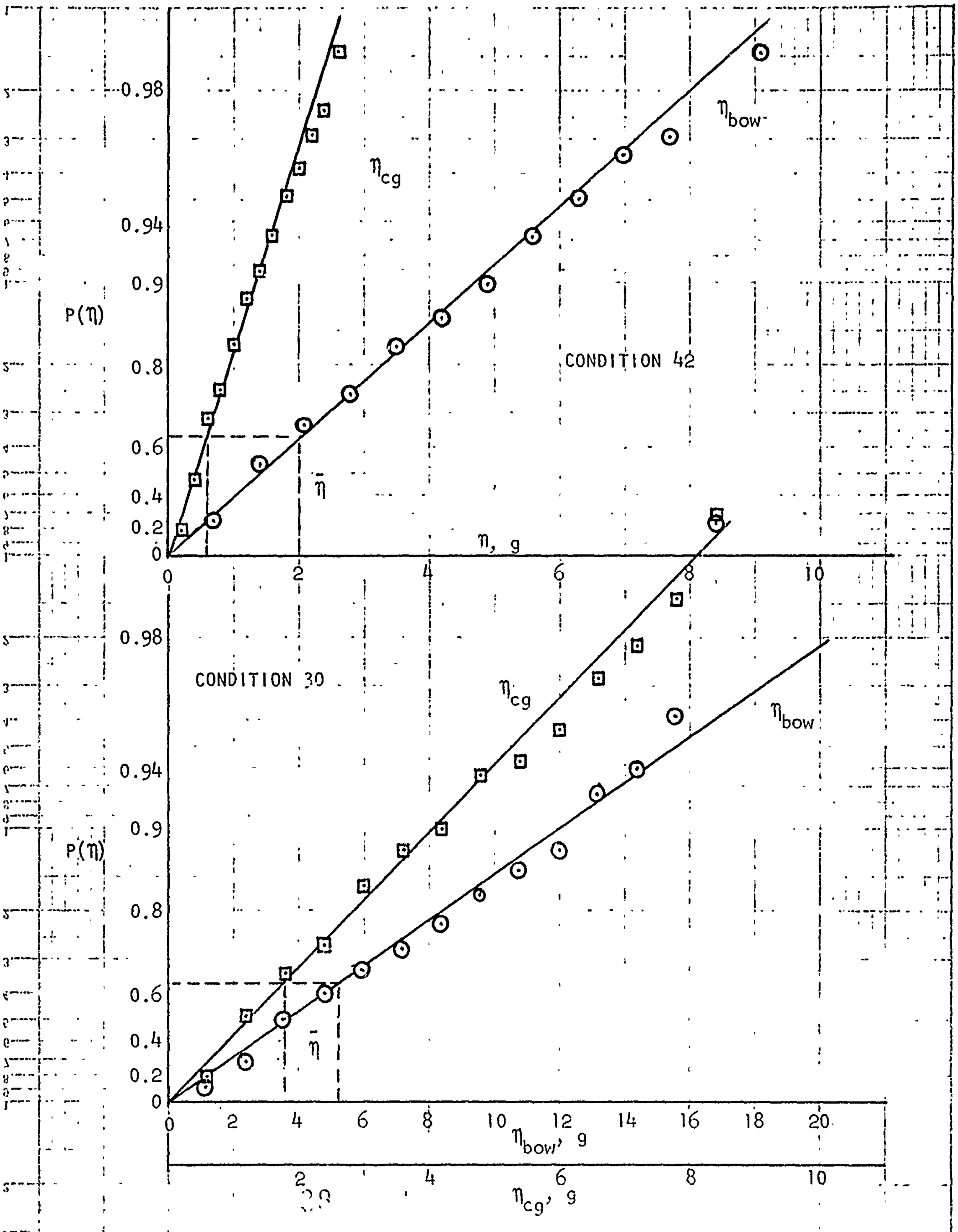


FIG. 7 TYPICAL ACCELERATION DISTRIBUTION

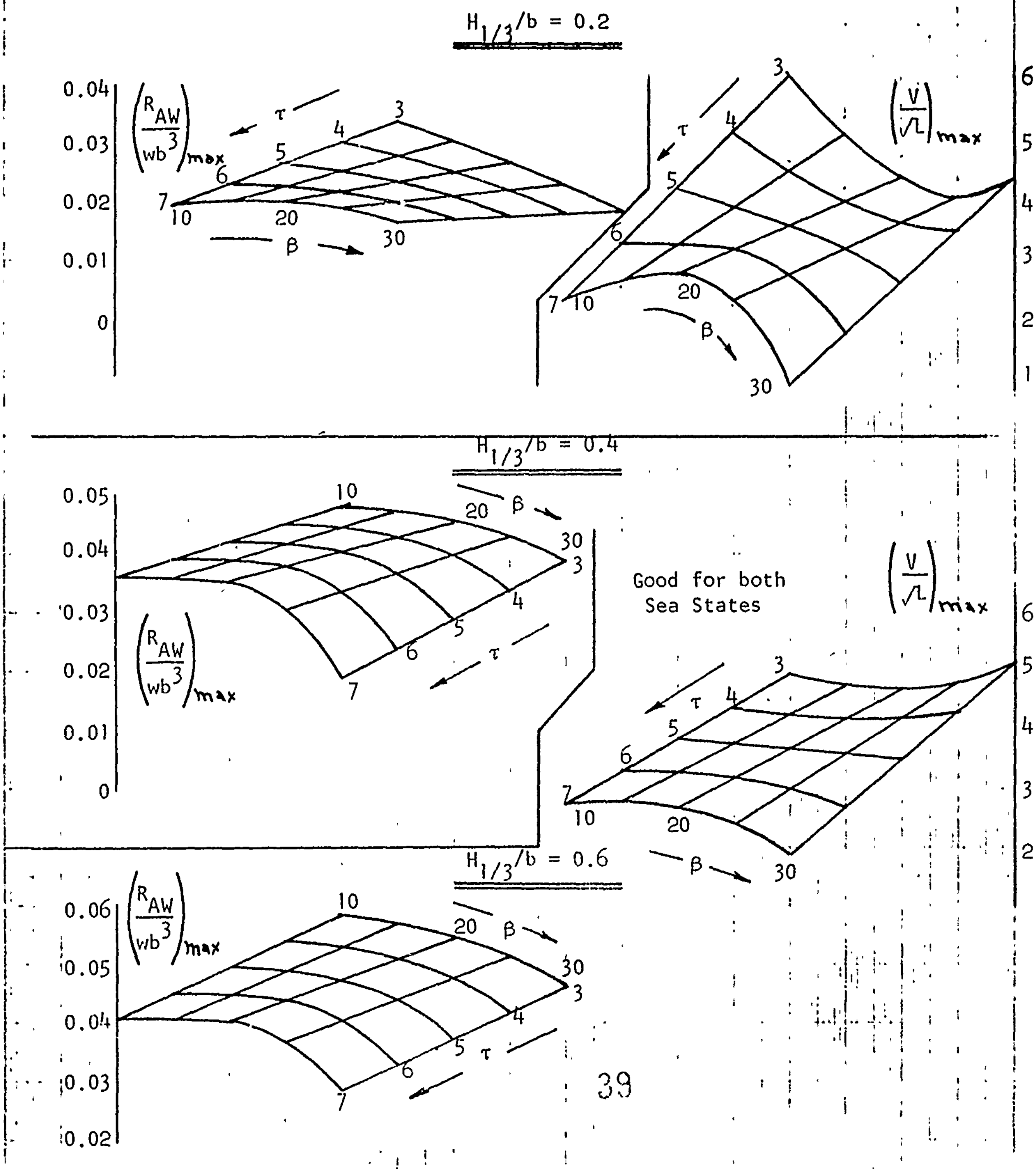
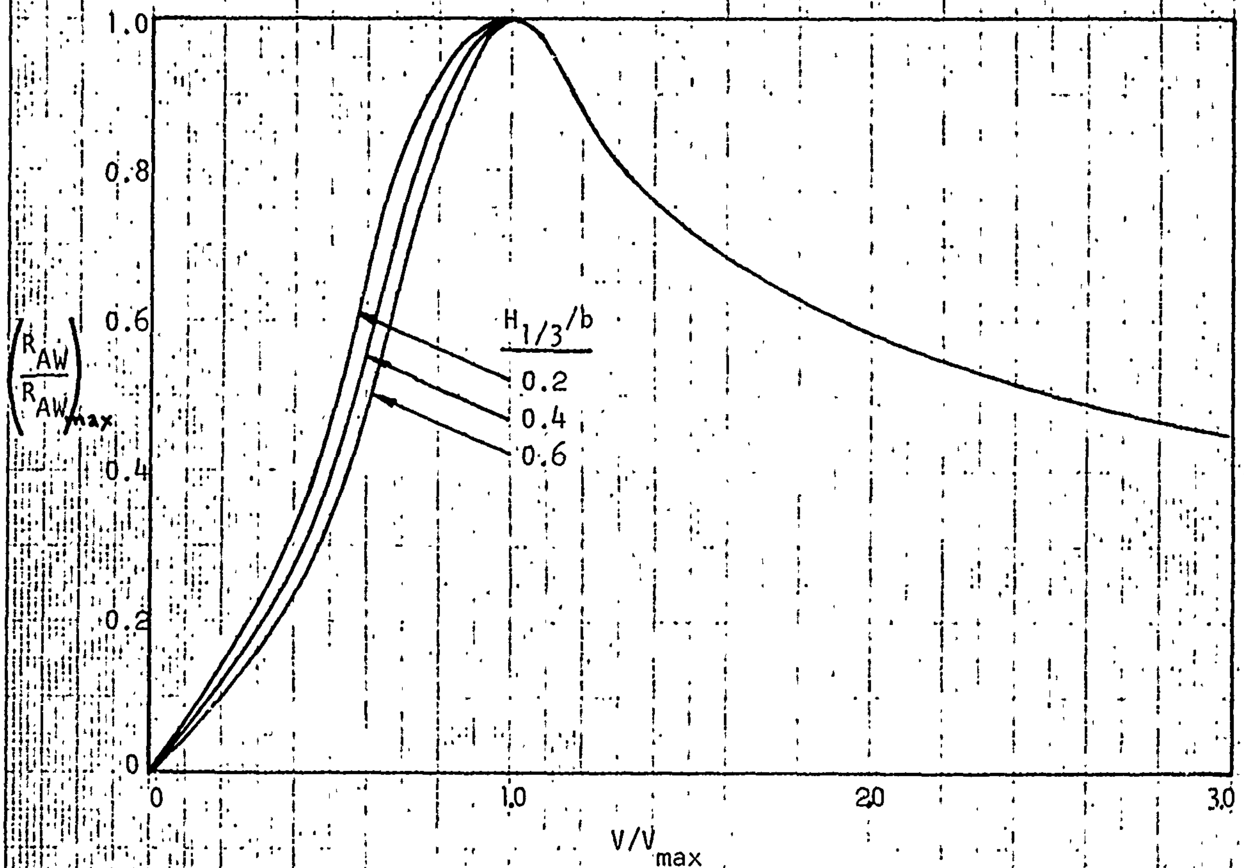


FIG. 8 MAXIMUM ADDED RESISTANCE AND SPEED
FOR C_Δ = 0.60 AND L/b = 5



$$\frac{R_{AW}}{wb^3} = \left(\frac{R_{AW}}{R_{AW_{max}}}\right) \times \left(\frac{R_{AW}}{wb^3}\right)_{max} \times E(V/\sqrt{L},\ C_\Delta,\ L/b,\ H_{1/3}/b)$$

FIG. 9 GENERALIZED ADDED RESISTANCE PLOT FOR $C_\Delta = 0.60$ AND $L/b = 5$

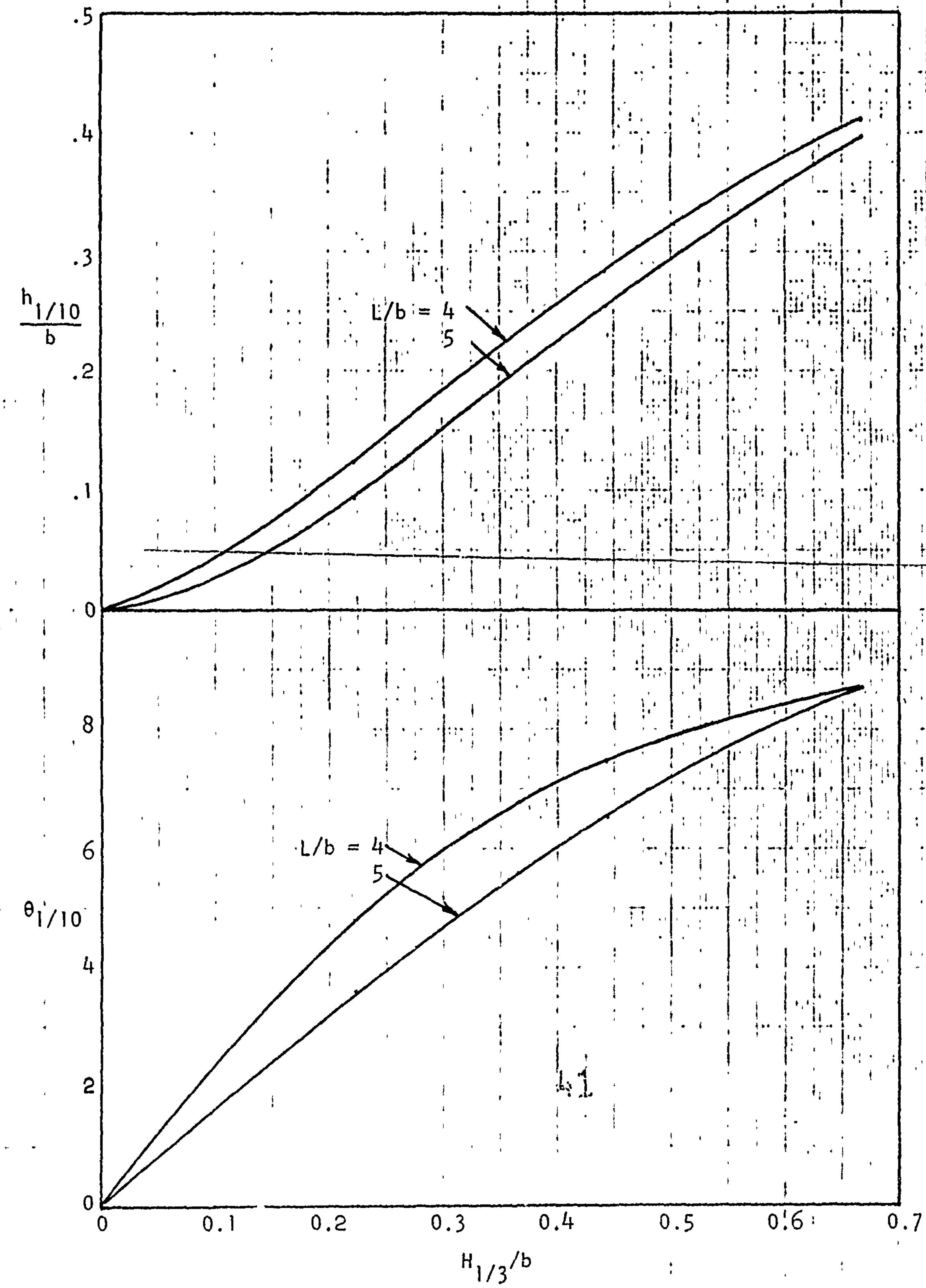


FIG. 10 1/10 HIGHEST MOTION AMPLITUDES AT $V/\sqrt{L} = 2$
($\tau = 4^{\circ}$, all C_{Δ}, all β)

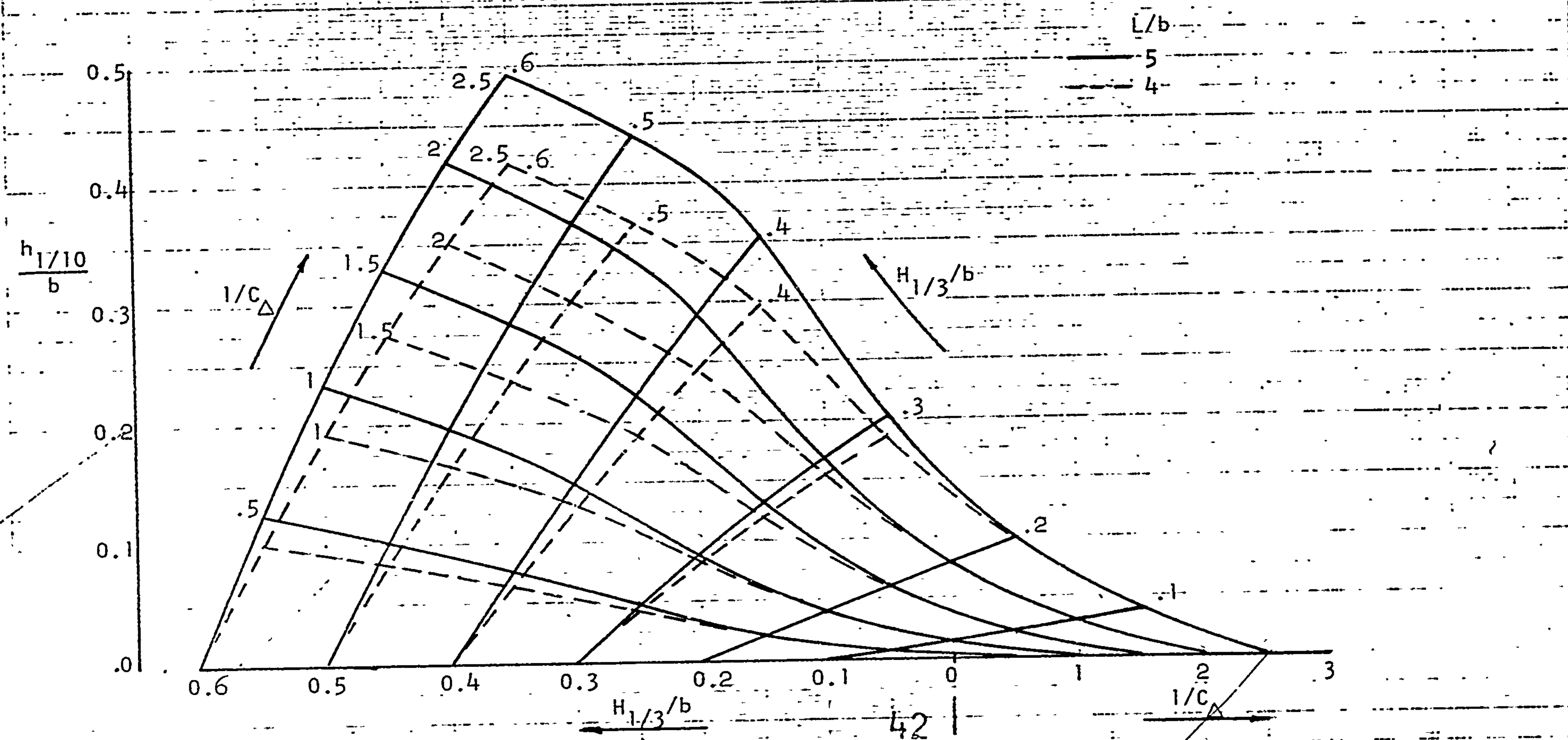


FIG. 11 1/10 HIGHEST HEAVE AMPLITUDE AT $V/\sqrt{L} = 4$

($\tau = 4^{\circ}$, all β)

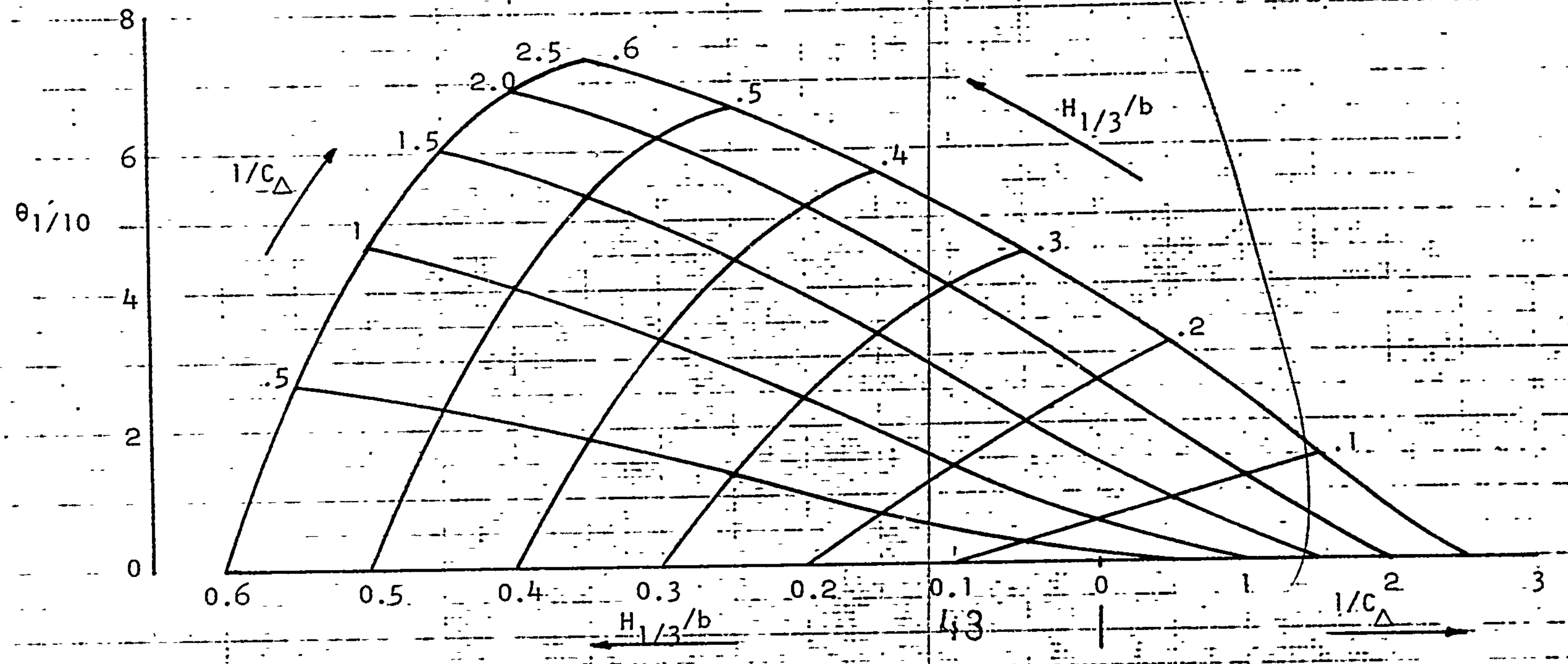


FIG. 12 1/10 HIGHEST PITCH AMPLITUDES AT $V/\sqrt{L}$ = 4

(τ = 4°, all β, L/b = 4 & 5)

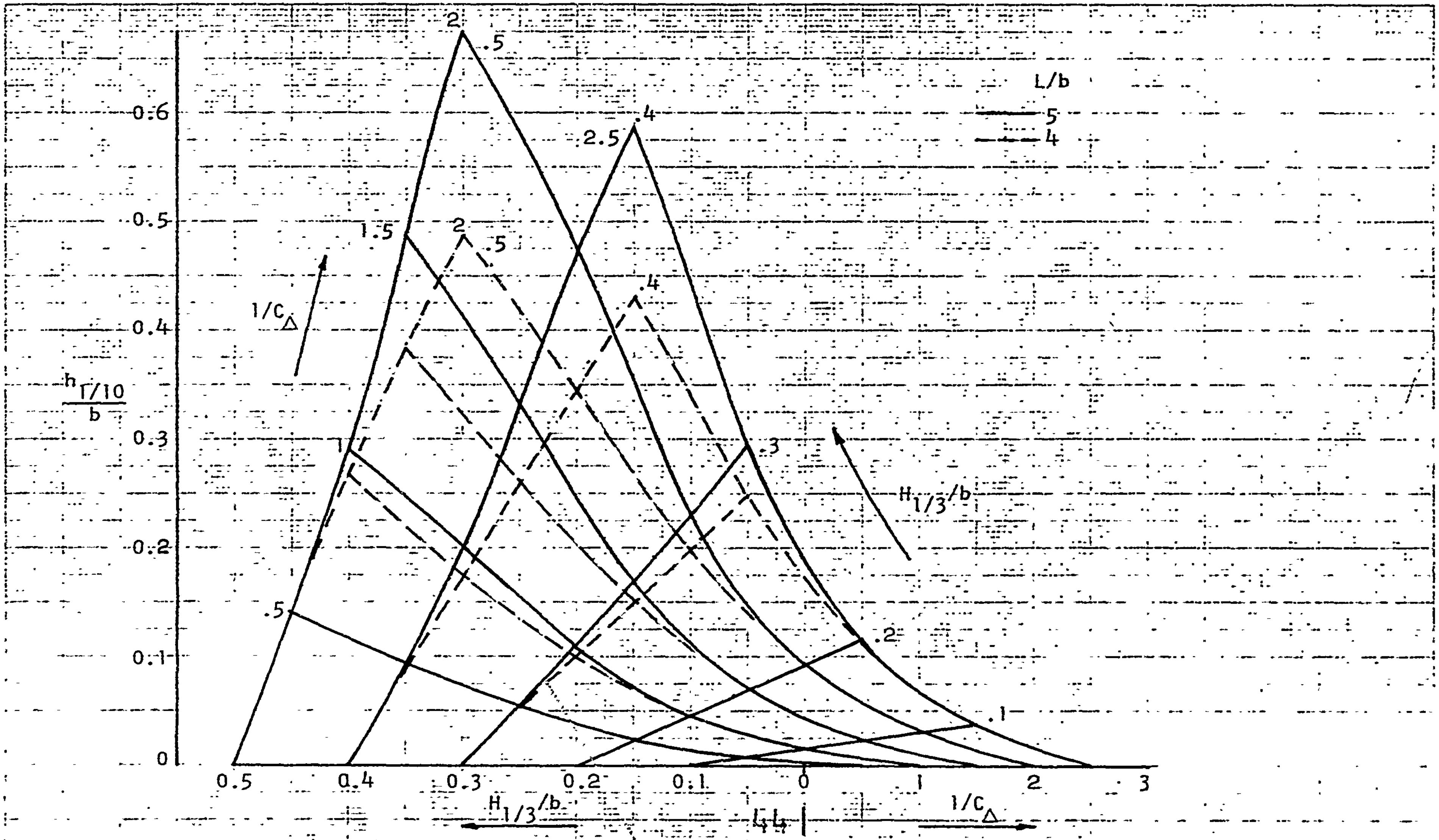


FIG. 13 1/10 HIGHEST HEAVE AMPLITUDES AT $V/\sqrt{L} = 6$

($\tau = 4^\circ$, $\beta = 20^\circ$)

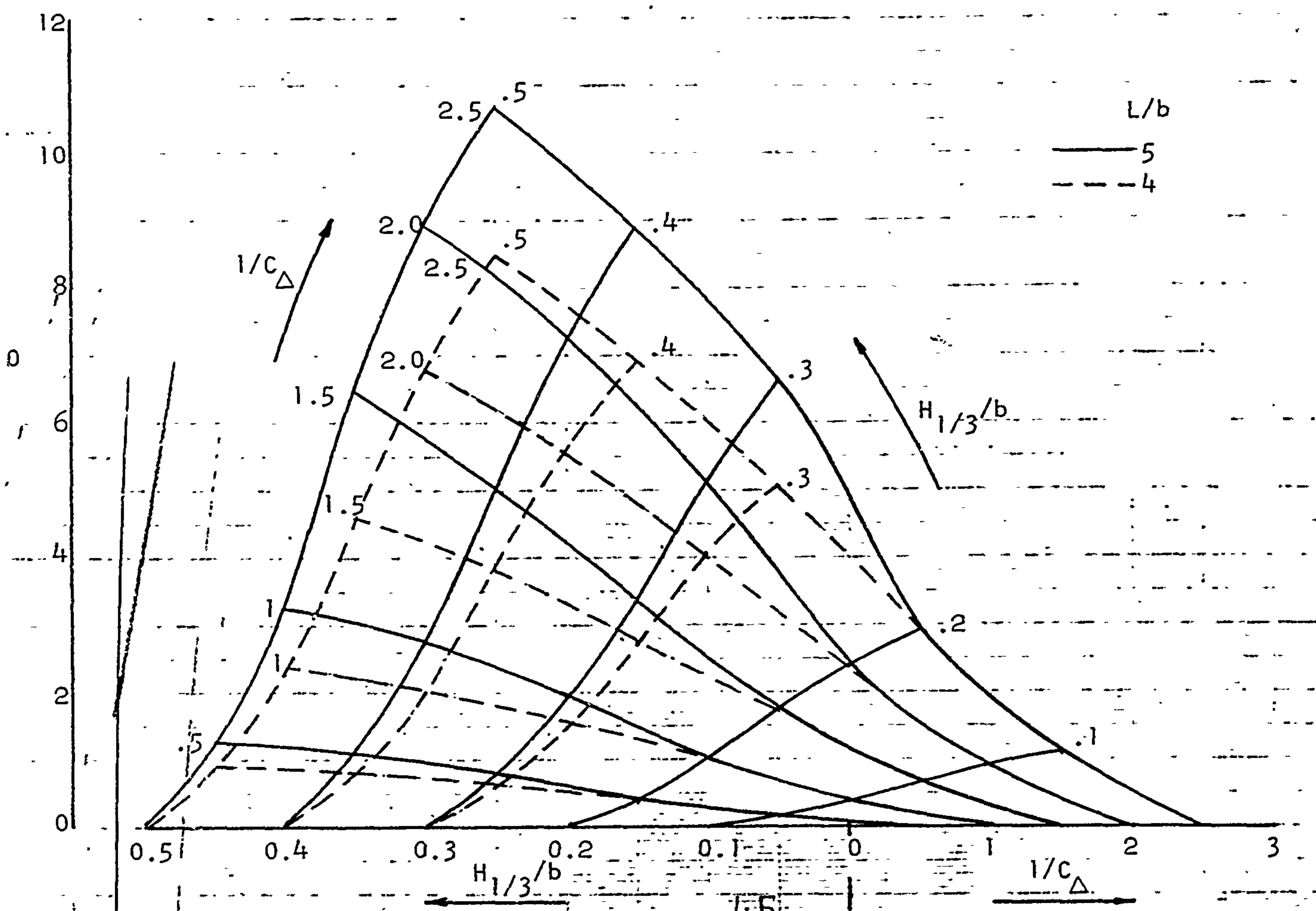


FIG. 14 1/10 HIGHEST PITCH AMPLITUDES AT $V/\sqrt{L} = 6$
($\tau = 4^\circ$, $\beta = 20^\circ$)

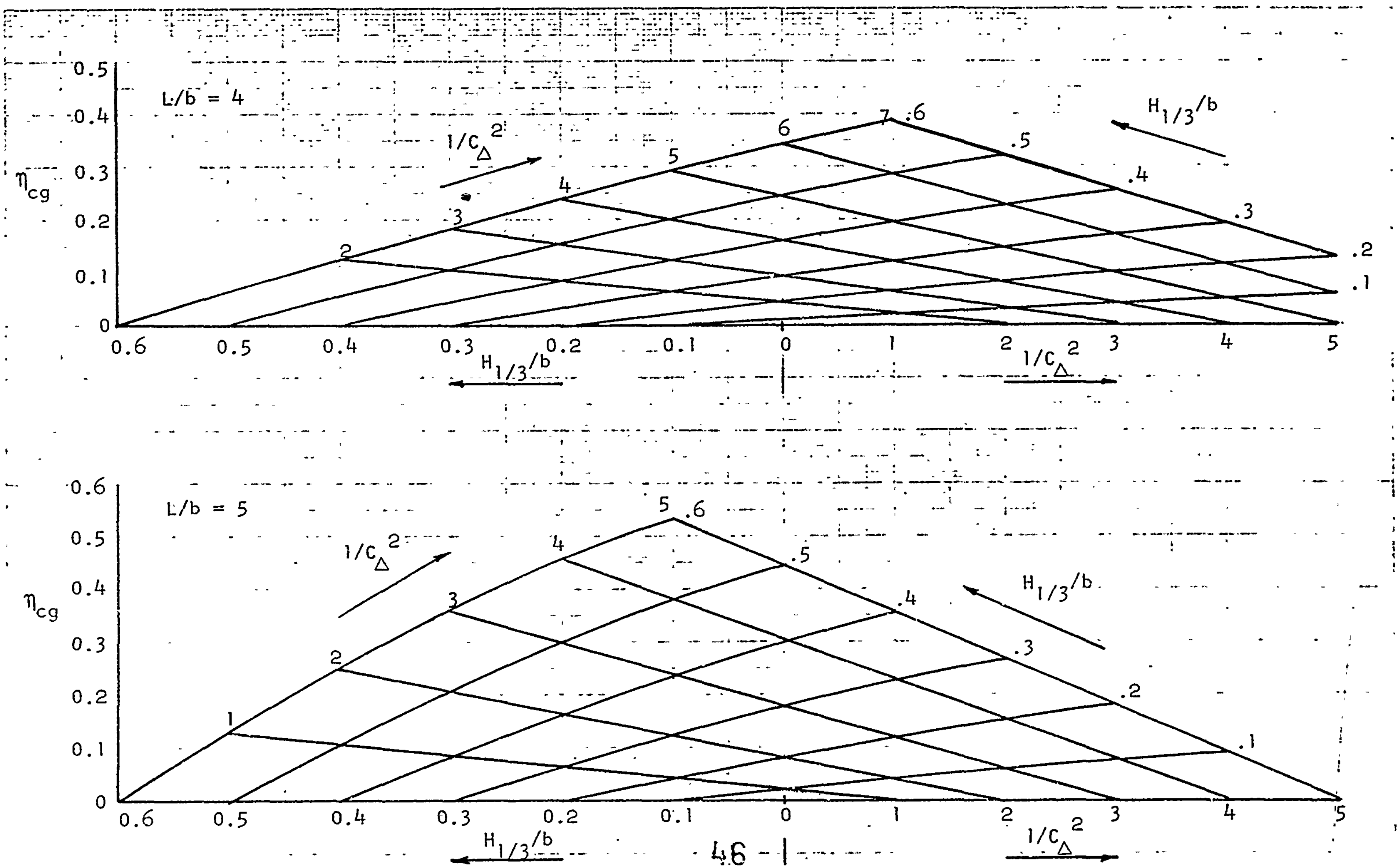


FIG. 15 AVERAGE CG ACCELERATION AT $V/\sqrt{L} = 2$
($\tau = 4^o$, $\beta = 20^o$)

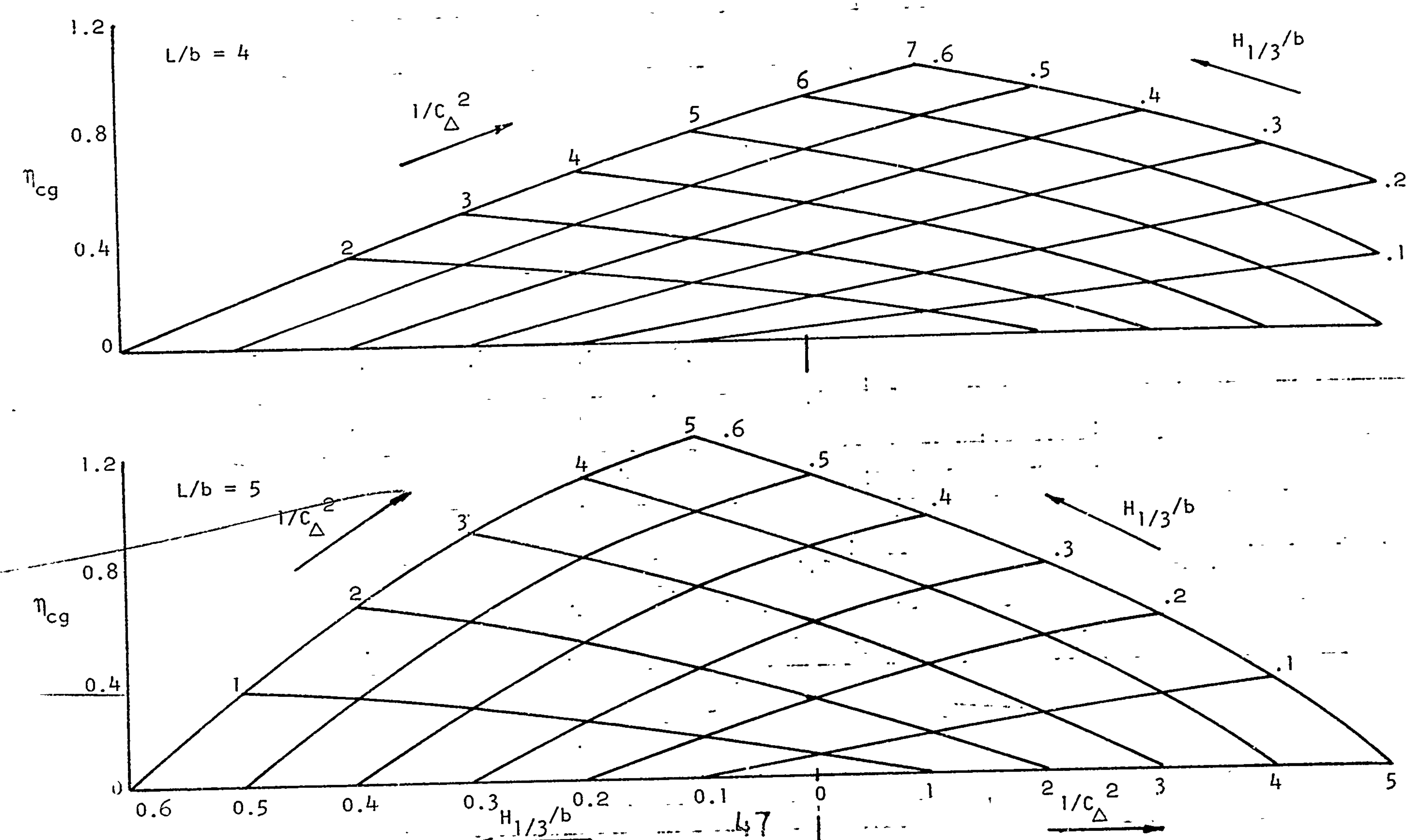


FIG. 16 — AVERAGE CG ACCELERATION AT $V/\sqrt{L} = 4$
($\tau = 4^o$, $\beta = 20^o$)

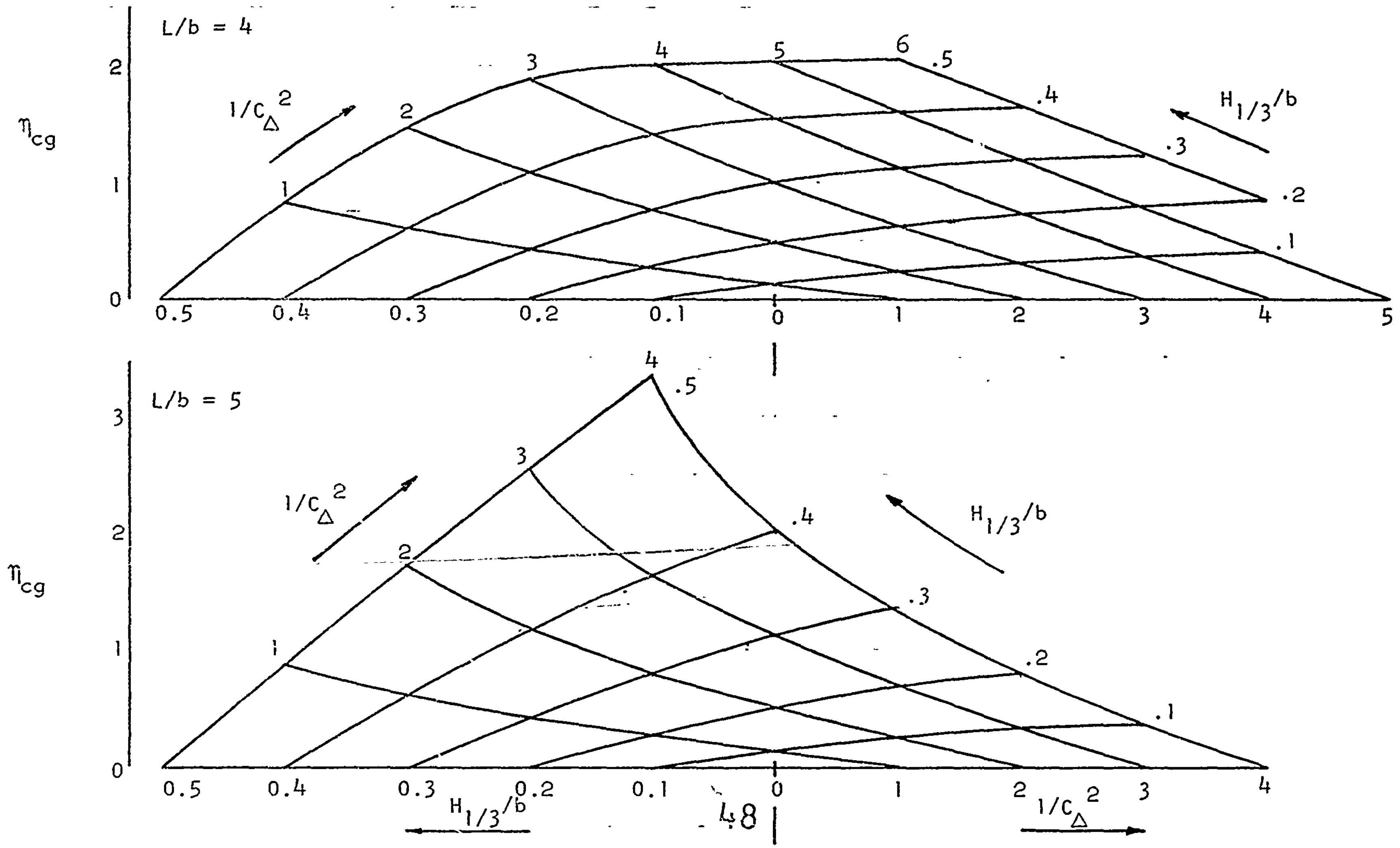


FIG. 17 AVERAGE CG ACCELERATION AT $V/\sqrt{L} = 6$
($\tau = 4^{o}$, $\beta = 20^{o}$)

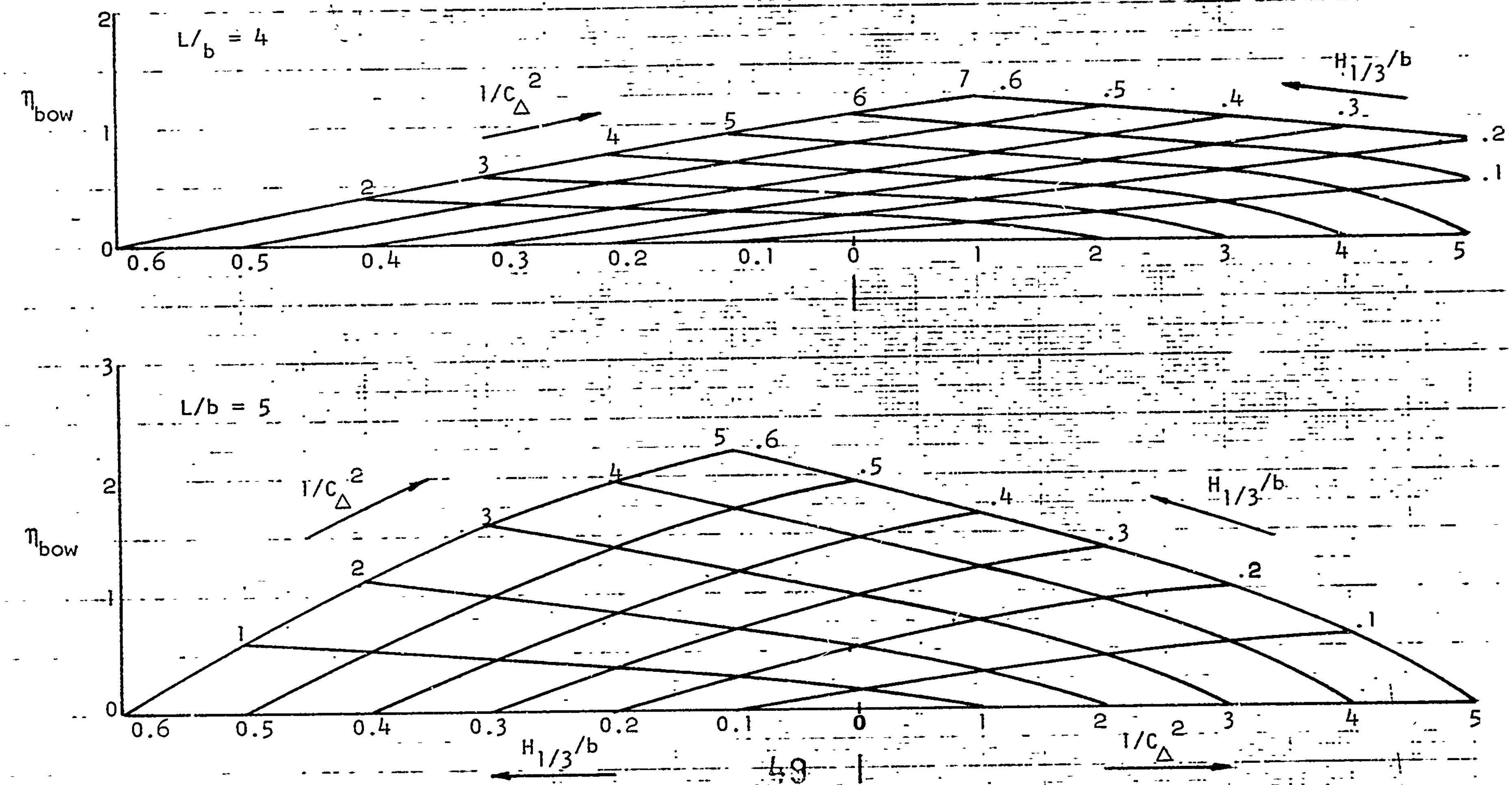


FIG. 18 AVERAGE BOW ACCELERATION AT $V/\sqrt{L}$ = 2
(τ = 4°, β = 20°)

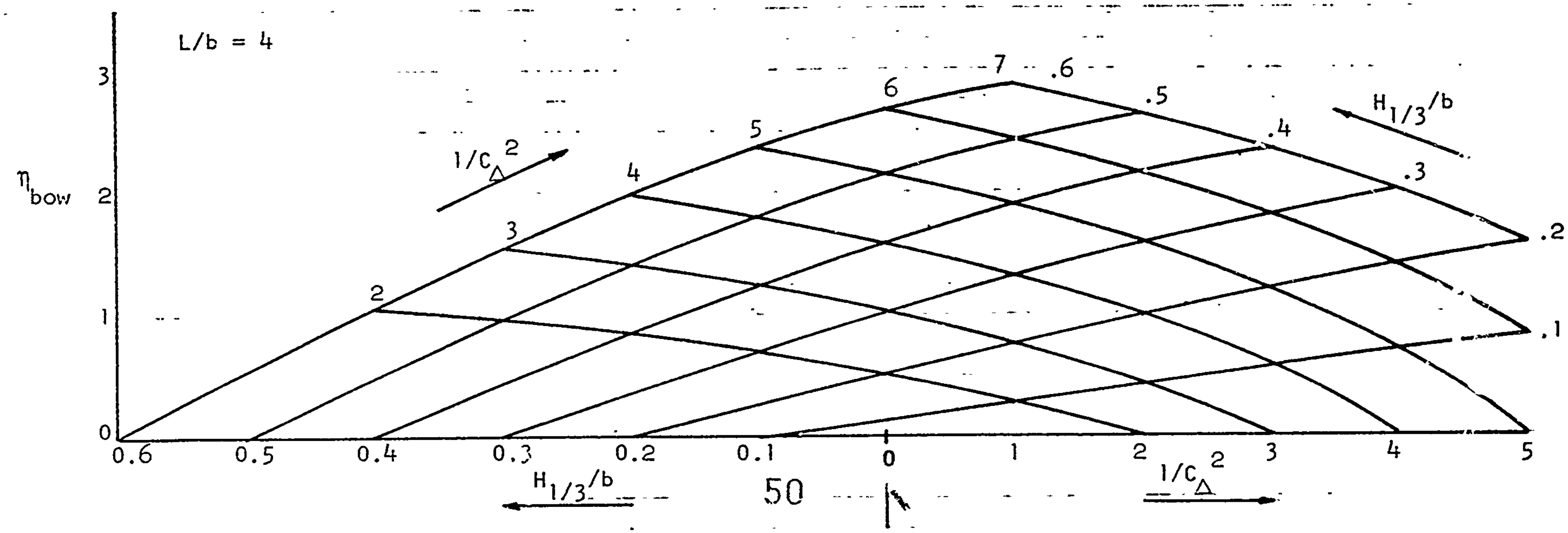


FIG. 19 AVERAGE BOW ACCELERATION AT $V/\sqrt{L} = 4$
($\tau = 4^o$, $\beta = 20^o$)

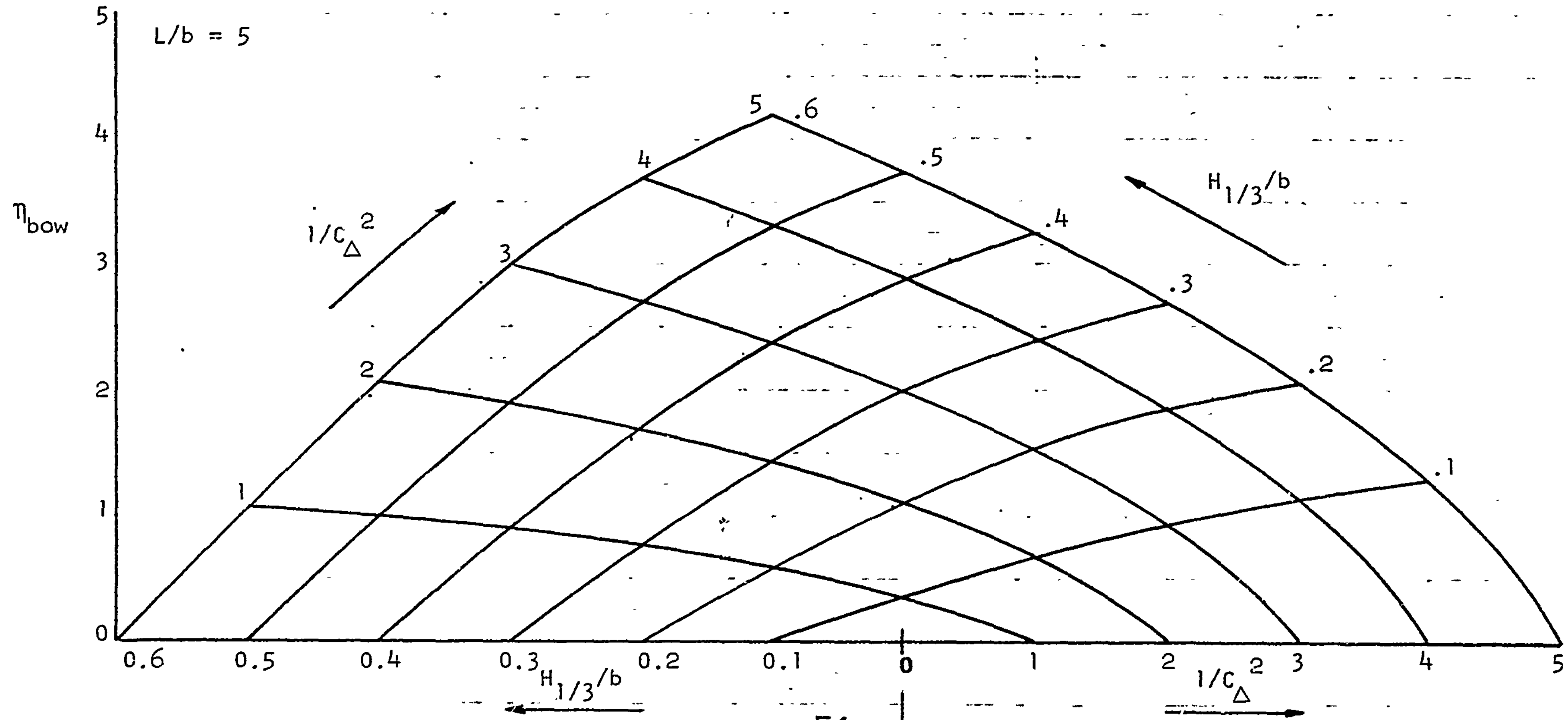


FIG. 20 AVERAGE BOW ACCELERATION AT $V/\sqrt{L}$ = 4
(τ = 4°, β = 20°, L/b = 5)

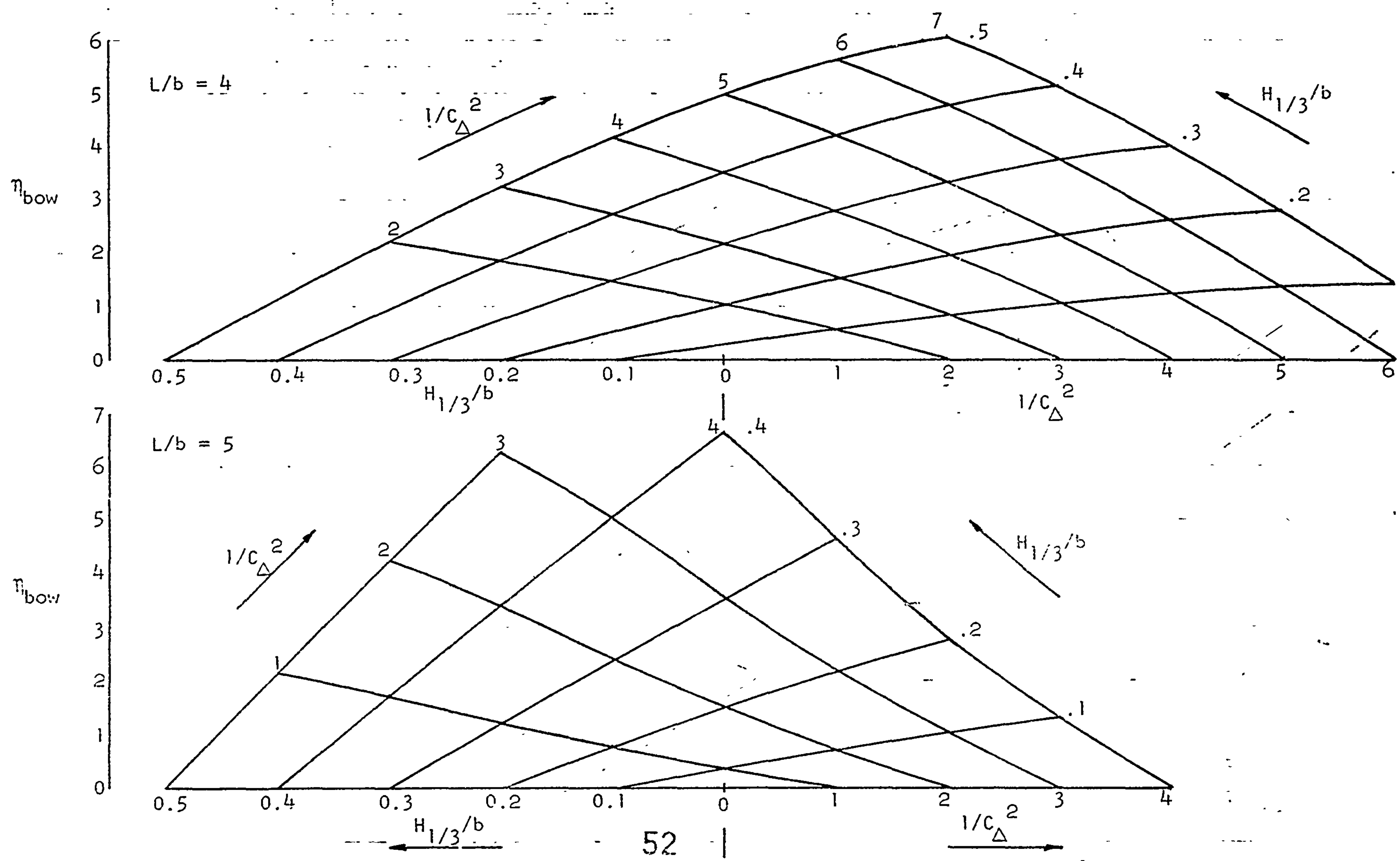


FIG. 21 AVERAGE BOW ACCELERATION AT $V/\sqrt{L} = 6$

($\tau = 4^{\circ}$, $\beta = 20^{\circ}$)

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APPENDIX I

CONSTANT SPEED VS. CONSTANT THRUST

The procedure used in evaluating planing hull performance in rough water has been to test at constant thrust. Observations of speed records and models under test, however, indicate little or no surging motion at high speed-length ratios. This would mean that if towed at constant speed, the model planing hull would behave exactly as though it were tested at constant thrust. To verify this at the low end of the speed range ($V/\sqrt{L} = 2$), a comparison was made of the boat's performance at both constant speed and constant thrust.

The 10^o deadrise model ($L/b = 5$, $C_\Delta = 0.60$, $\tau = 4^o$) was tested in a moderate and relatively large sea state ($H_{1/3}/b = 0.444$ and 0.667) using both test procedures. The results of the comparison follows:

The total resistance in waves (Table II) for the moderate Pierson-Moskowitz (PM) spectrum ($H_{1/3}/b = .444$) is $R_W/\Delta = .136$ (constant speed) compared with $R_W/\Delta = .132$ (constant thrust). In the larger wave ($H_{1/3}/b = .667$) the comparison is even better; $R_W/\Delta = .138$ (constant speed) vs. $R_W/\Delta = .137$ (constant thrust).

The motion distributions for both heave and pitch are included in Figs. I-1 through I-4. The results in both sea states for crests and troughs are identical. The table on the following page provides good evidence that either test procedure may be used for the planing hull.

The results of the constant thrust vs. constant speed procedure on accelerations is shown in Figs. I-5 and I-6. You will note that the plot is on linear graph paper and not on semi-log paper as would be the case if the acceleration distributions were exponential. The reason for this is the check on test procedure was the first batch of runs made in the towing tank and no attempt was made to filter out the model response at this stage. Consequently the distribution of wave induced accelerations is somewhat distorted by inclusion of small accelerations which may be noise and by excessively high accelerations which have been magnified by the model response. Nevertheless the relative distribution between the two test procedures is found to be in good agreement. The average values are presented in the second table on the following page.

Comparison of Motions
Constant Speed vs. Constant Thrust
($V/\sqrt{L} = 2$, $C_\Delta = 0.60$, $L/b = 5$, $\tau = 4^o$, $\beta = 10^o$)

Sea State	Quantity		Heave Motions (Model in.)		Pitch Motions (deg)	
$H_{1/3}/b$			C.S.	C.T.	C.S.	C.T.
.444		$\bar{X}$	1.06	1.04	2.81	2.76
		X_{DC}	0.0	-.16	3.98	3.77
	Crests	r	.0522	.0515	.0608	.0672
		X_{50}	1.02	1.00	2.72	2.67
		X_{90}	1.97	1.94	5.33	5.28
	Troughs	r	.0174	.0515	.0338	.0420
		X_{50}	1.00	1.00	2.69	2.64
		X_{90}	1.86	1.94	5.09	5.06
.667		$\bar{X}$	1.45	1.49	3.63	3.20
		X_{DC}	-.03	-.08	3.93	3.87
	Crests	r	.0952	.1087	.0222	.0813
		X_{50}	1.41	1.46	3.45	3.10
		X_{90}	2.91	3.08	6.44	6.27
	Troughs	r	.0190	.0435	.0370	.0976
		X_{50}	1.37	1.43	3.47	3.11
		X_{90}	2.55	2.74	6.60	6.47

Comparison of Average Accelerations
Constant Speed vs. Constant Thrust

Sea State	Bow Accelerations		C.G. Accelerations	
$H_{1/13}/b$	C.S.	C.T.	C.S.	C.T.
.444	1.36	1.49	.37	.44
.667	2.08	2.16	.63	.60

The constant speed technique for the planing hull, in the speed range investigated, is therefore a good test procedure to use in the towing tank.

APPENDIX I

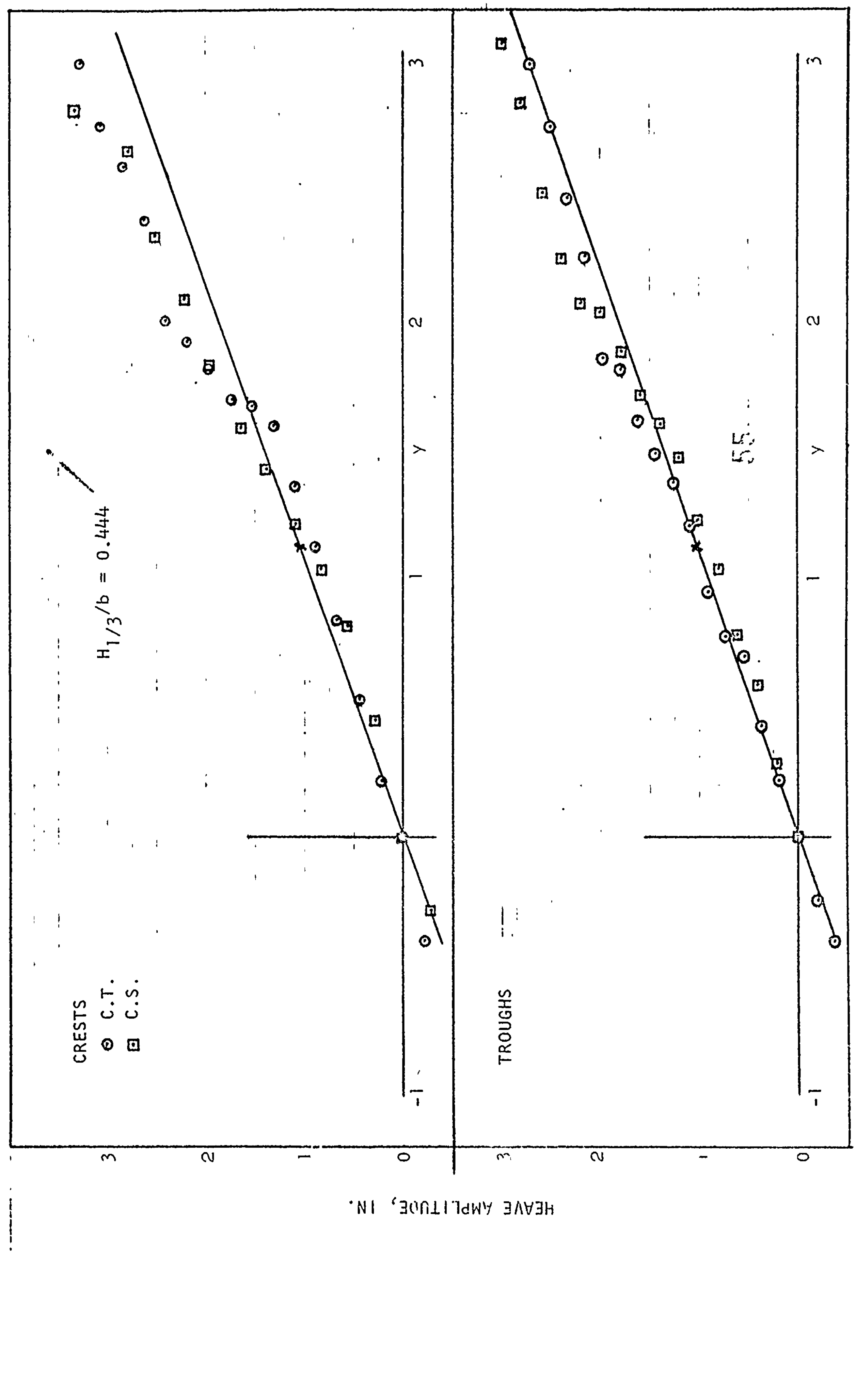

FIG. I-1 HEAVE MOTION: CONSTANT SPEED VS. CONSTANT THRUST - CONDITION A

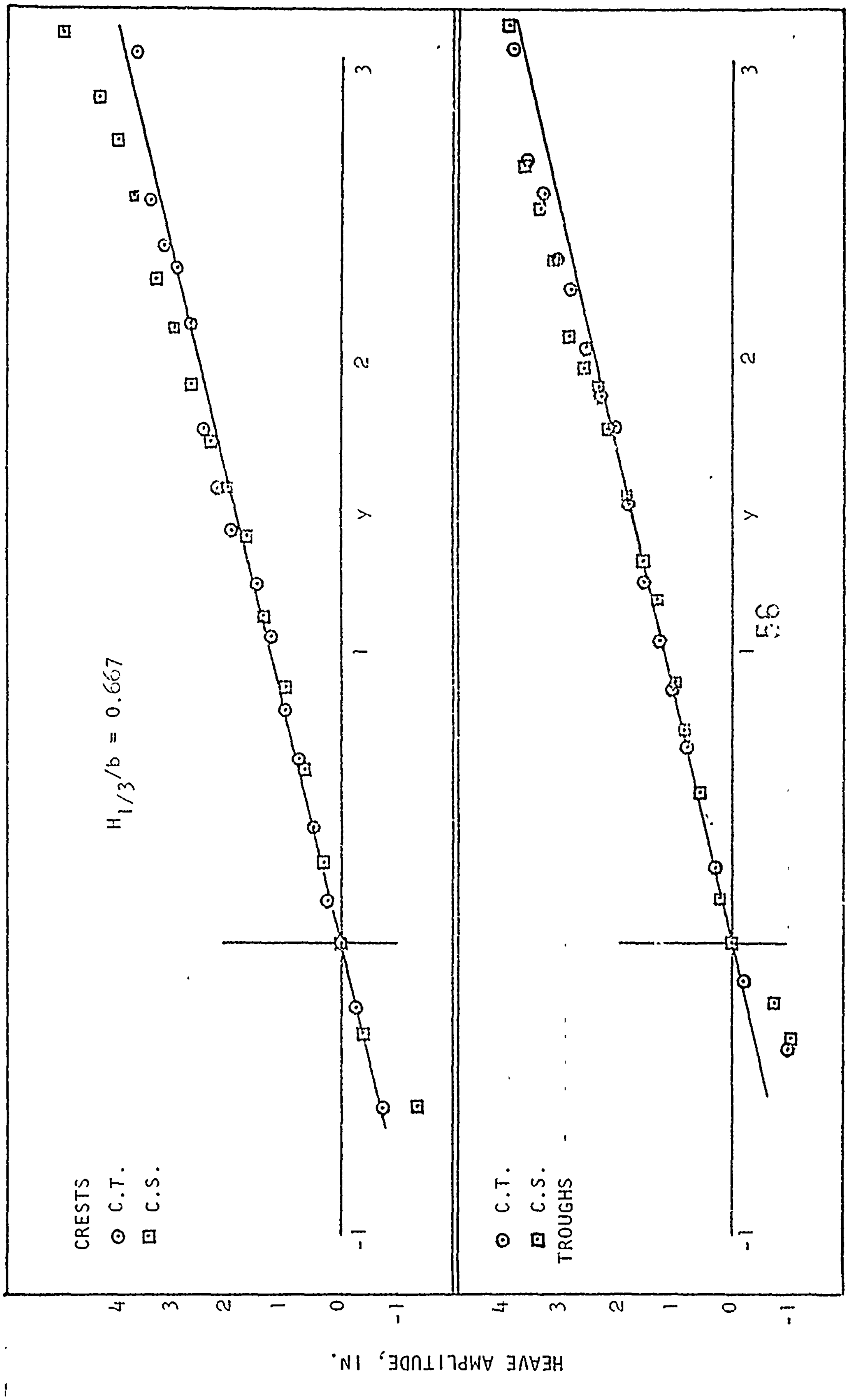

FIG. I-2 HEAVE MOTION: CONSTANT SPEED VS. CONSTANT THRUST - CONDITION A

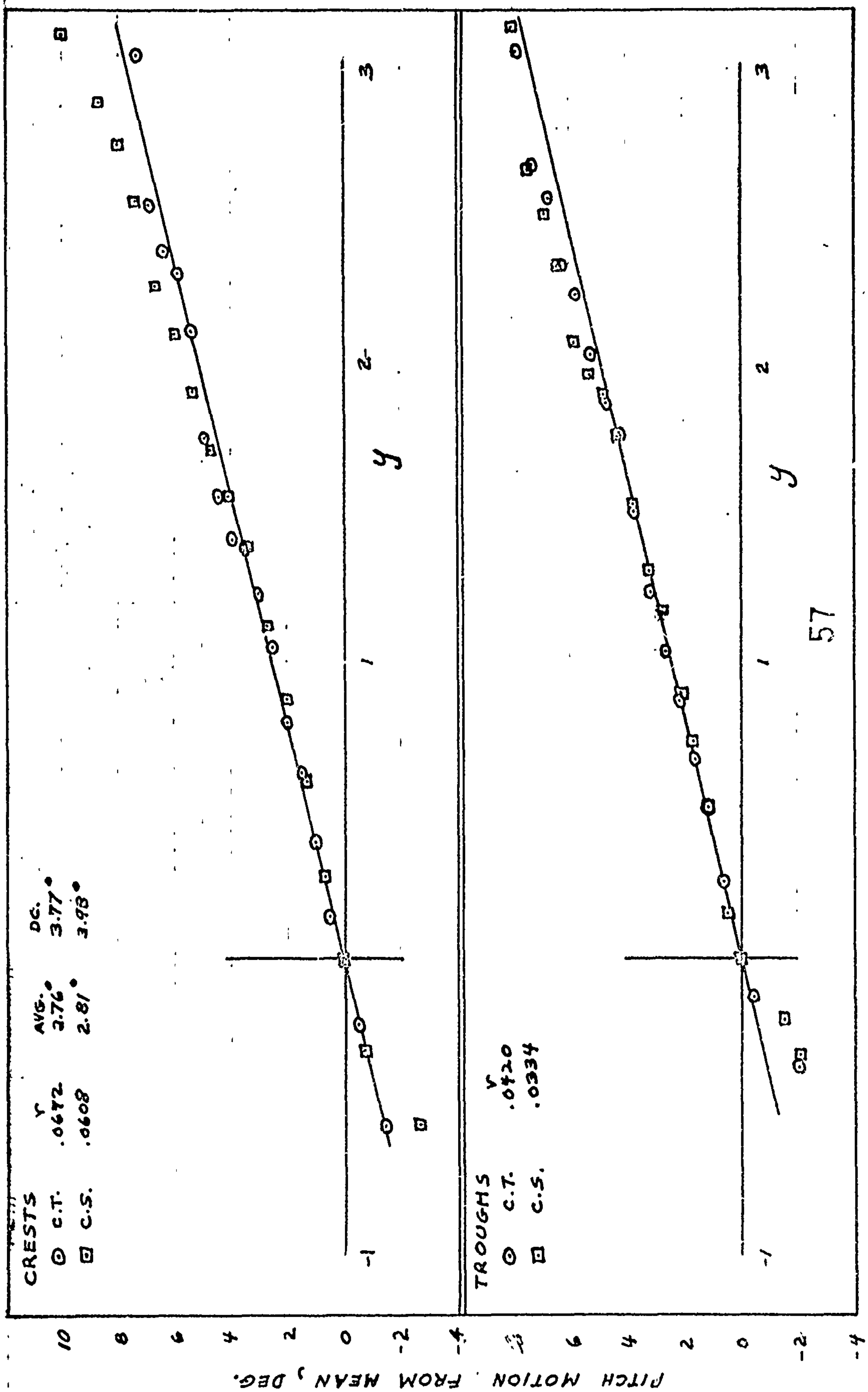

FIG. I-3 PITCH MOTION : CONSTANT SPEED VS. CONSTANT THRUST
($V/\sqrt{L} = 2$, $\beta = 10°$, $L/b = 5$, $C_\Delta = 0.60$, $\tau = 4°$, $H_{1/3}/b = 0.444$)

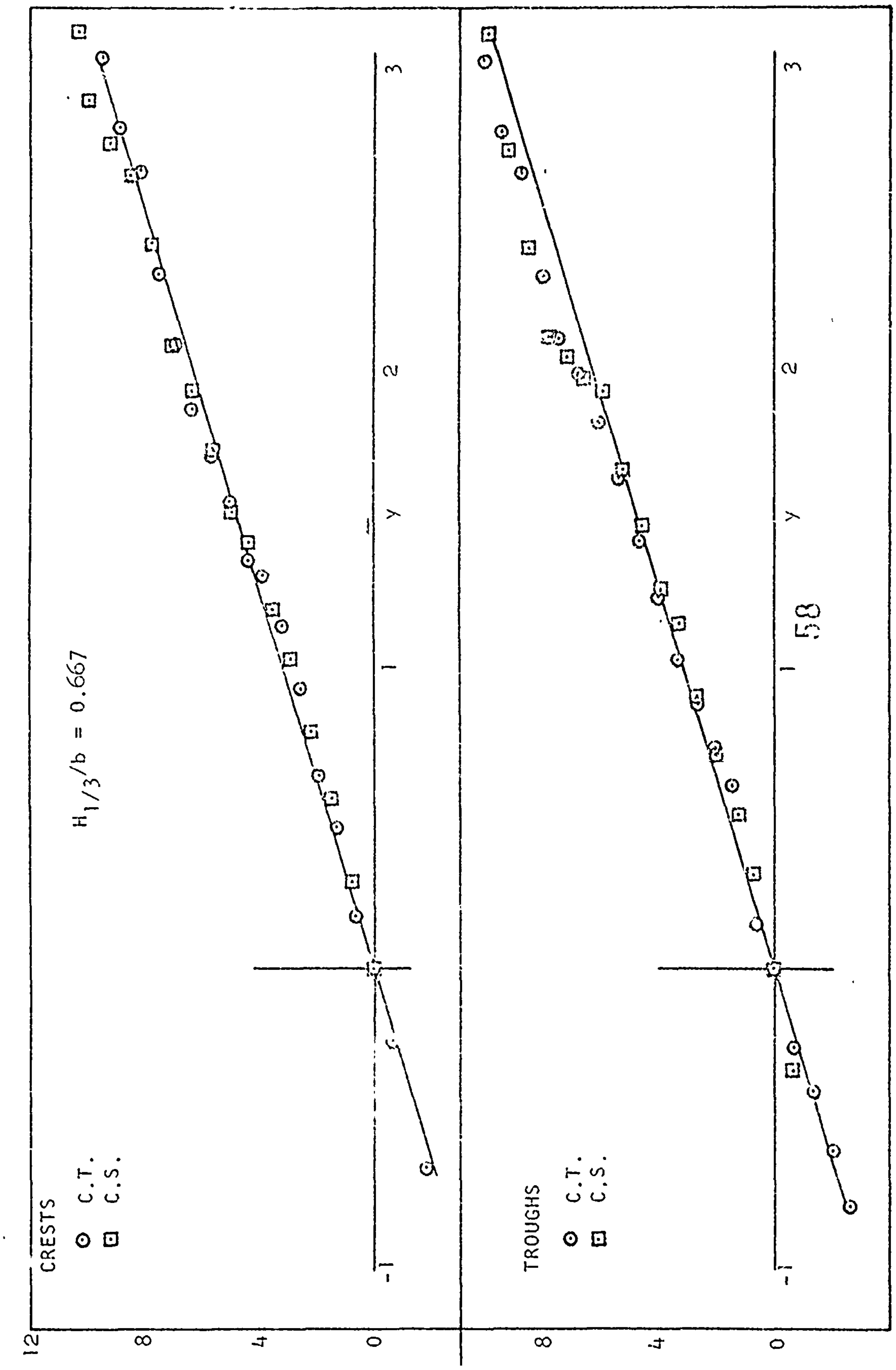

FIG. I-4 PITCH MOTION: CONSTANT SPEED VS. CONSTANT THRUST - CONDITION A

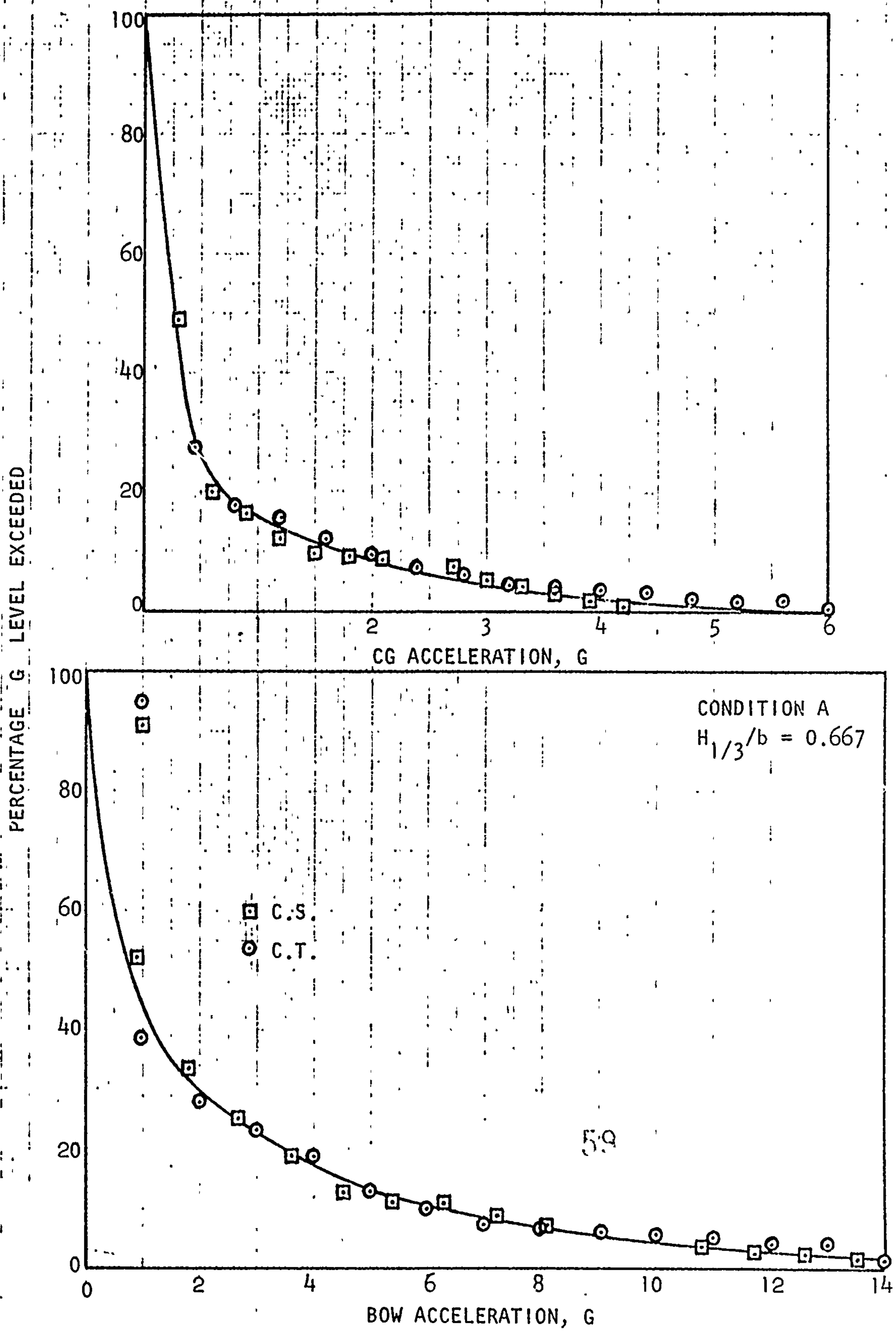

FIG. I-5 COMPARISON CONSTANT SPEED VS. CONSTANT THRUST

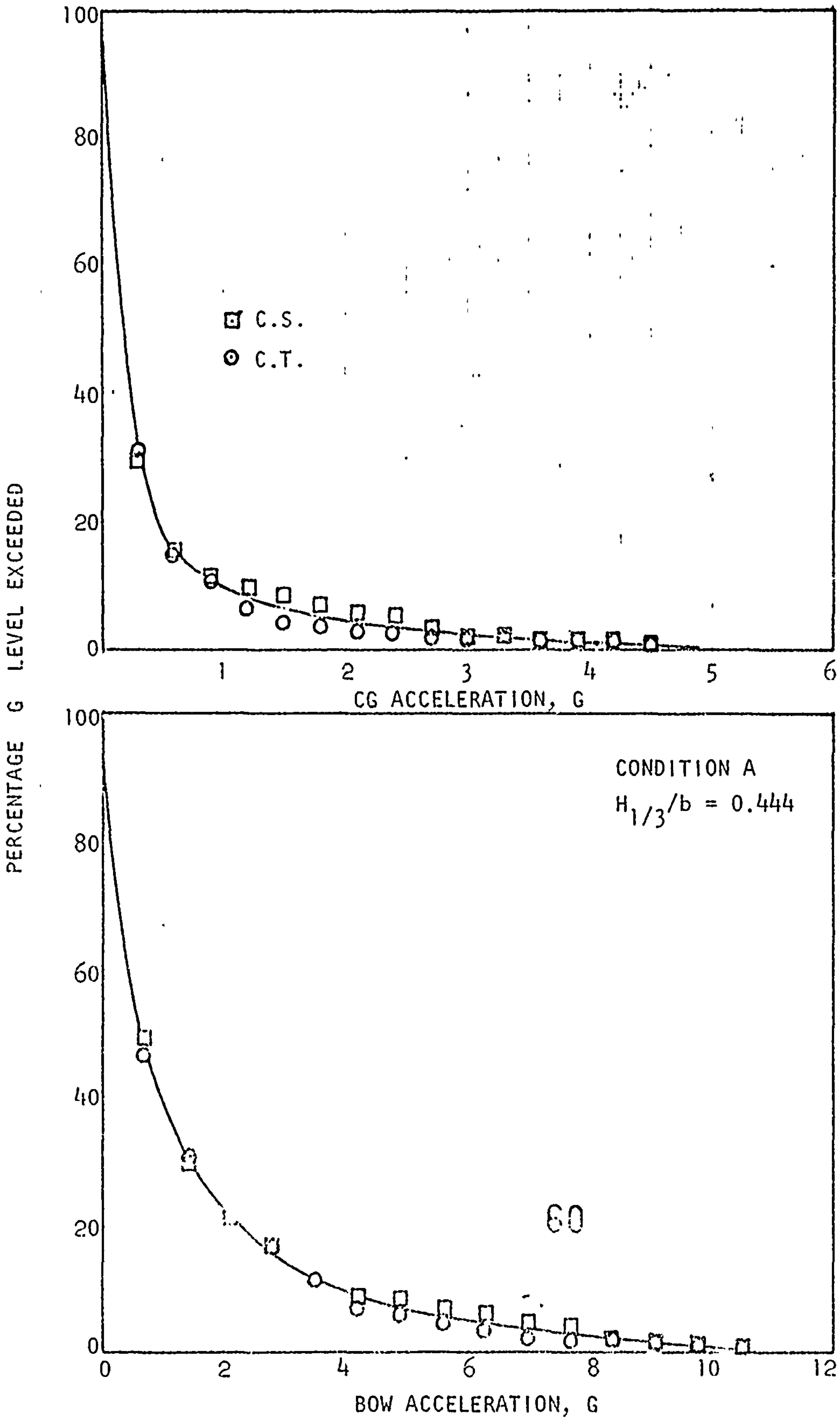

FIG. I-6 COMPARISON CONSTANT SPEED VS. CONSTANT THRUST

APPENDIX II

DISTRIBUTIONS

A. Motions

If the motion amplitude is non-dimensionalized by the root-mean-square value to give y, then the integral of the distribution that gives the probability of y exceeding a given value is

$$Q(y,\epsilon) = \frac{1}{(2\pi)^{1/2}}\left[\int_{y/\epsilon}^{\infty} e^{-\frac{1}{2}x^2}dx + (1-\epsilon^2)^{1/2} e^{-\frac{1}{2}y^2}\int_{-\infty}^{\frac{y(1-\epsilon^2)^{1/2}}{\epsilon}} e^{-\frac{1}{2}x^2}dx\right]$$

This is the expression for the cumulative distribution of maxima arising from a broad frequency spectrum (ref. 4). It may be termed a "Generalized Rayleigh Distribution." For small values of r or e, it may be termed a "Distorted Rayleigh Distribution."

Note when $\epsilon \to 0$, $r \to 0$

$$Q(y,0) = \begin{Bmatrix} 1 & (y \leq 0) \\ e^{-1/2y^2} & (y \geq 0) \end{Bmatrix}$$

which is equal to the Rayleigh distribution.

When $\epsilon \to 1$, $r \to 1/2$

$$Q(y,1) = \frac{1}{(2\pi)^{1/2}}\int_y^{\infty} e^{-1/2x^2}dx$$

which is equal to the Gaussian distribution. The number ϵ can be evaluated from experiments by measuring the proportion r of negative maxima and then calculating ϵ from

$$\epsilon^2 = 1 - (1-2r)^2$$

For the purposes of this report, it was necessary to solve for y, given Q and ϵ. Thus the above equation had to be solved by an iterative scheme on the computer. Values of y_{50}, $y_{1/3}$, y_{90}, $y_{1/10}$, and y_{99} were

obtained as some of the more common quantities of interest and are plotted as a function of r in Fig. II-1. The average value can be solved in closed form as

$$\bar{y} = \sqrt{\pi/2}\,(1-2r)$$

The average crest or trough of the heave or pitch motion is plotted opposite $\bar{y}$ in order to draw the theoretical straight line through the data.

To obtain the average of the 1/10 highest motions from the motions at the 90% point, multiply by 1.22. This is approximately true over the range of test data.

B. Accelerations

The distribution which describes the accelerations is exponential in form. The probability, Q, of the acceleration, η, exceeding a given value is

$$Q(\eta) = e^{-\eta/\bar{\eta}}$$

where $\bar{\eta}$ = average peak acceleration.

On semi-log paper this equation plots as a straight line and is shown in Fig. II-2. Thus the probability level for any value of acceleration can be easily read off the chart as some multiple of the average value. Also of interest is the average of the $1/N$ highest accelerations. This is given by

$$\bar{\eta}_{1/N} = \bar{\eta}(1 + \ln N)$$

Thus for the 1/10 highest values

$$\bar{\eta}_{1/10} = 3.30\,\bar{\eta}$$

A plot of $\bar{\eta}_{1/N}$ as a function of N is also included in Fig. II-2.

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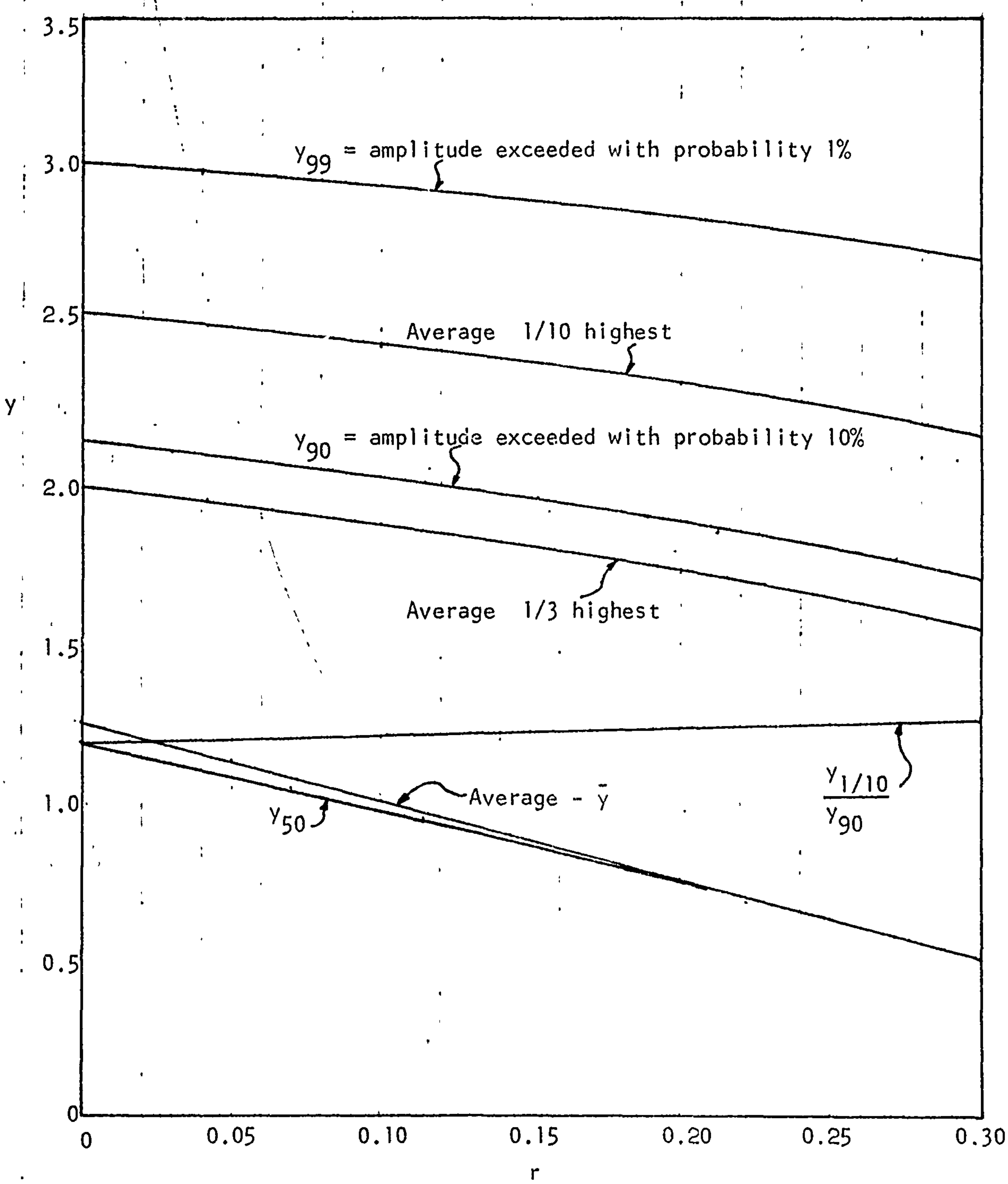

FIG. II-1 SOME y VALUES OF INTEREST

APPENDIX II

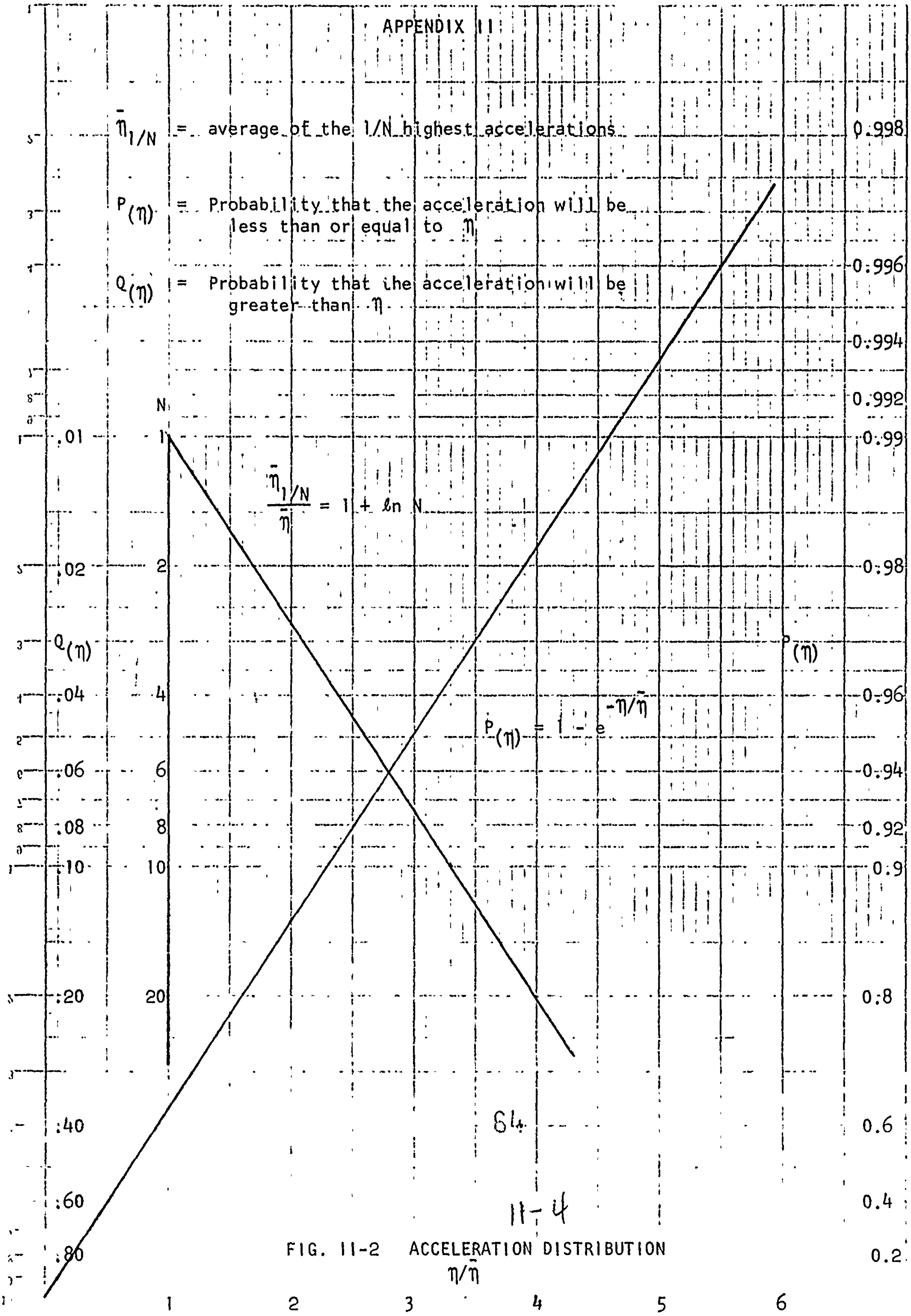

FIG. II-2 ACCELERATION DISTRIBUTION

APPENDIX III

WORK SHEET AND CORRECTIONS FOR PREDICTING PLANING HULL PERFORMANCE

CORRECTIONS

I. ADDED RESISTANCE - CORRECTIONS FOR LOAD AND LENGTH/BEAM RATIO

$$\left(\frac{R_{AW}}{wb^3}\right)_{final} = \left(\frac{R_{AW}}{wb^3}\right)_{charts} \times E$$

where E is a function of speed

$V/\sqrt{L}$	
2	$E = 1 + \left[\frac{(L/b)^2}{25} - 1\right] \Big/ 1 + .895\left(\frac{H_{1/3}}{b} - .6\right)$
4	$E = 1 + 10\ H_{1/3}/b(C_\Delta/L/b - .12)$
6	$E = 1 + 2\ H_{1/3}/b\left[.9(C_\Delta - .6) - .7(C_\Delta - .6)^2\right]$

II. MOTIONS - TRIM AND DEADRISE CORRECTIONS

$$(h_{1/10}/b)_{final} = (h_{1/10}/b)_{charts} \times [F \times G]$$

$$F = 1 + \frac{V/\sqrt{L}}{24} \times (\tau - 4^\circ)$$

$$G = .56 + .11\ V/\sqrt{L} + .11\left(\frac{\beta}{10}\right)^2 \left[1 - \frac{V/\sqrt{L}}{4}\right]$$

Also note

$G = 1 \qquad V/\sqrt{L} \leq 4$

$G = G \qquad V/\sqrt{L} \geq 4$

III. ACCELERATIONS - TRIM AND DEADRISE CORRECTIONS

$$\eta_{final} = \eta_{charts} \times \left[\frac{\tau}{4^\circ}\left(5/3 - \frac{\beta}{30^\circ}\right)\right]$$

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PLANING HULL PERFORMANCE

WORK SHEET

I. TABULATE GIVEN INFORMATION

Δ , Displacement, lb

L , Overall length, ft

$\bar{b}$, Average beam, ft

$\bar{\beta}$, Average deadrise, deg

V , Speed, kts

τ , Smooth water running trim, deg

$H_{1/3}$, Significant wave height, ft

Δ	L	$\bar{b}$*	$\bar{\beta}$*	V	τ	$H_{1/3}$

*Averaged over aft 80% of boat

II. CALCULATE PARAMETERS

$w\bar{b}^3$ = ______

$1/C_\Delta$ = ______

$1/C_\Delta^2$ = ______

$C_\Delta/L/\bar{b}$ = ______

	C_Δ	$L/\bar{b}$	$\bar{\beta}$	$V/\sqrt{L}$	τ	$H_{1/3}/\bar{b}$
Limits	.3-.9	3-6	10-30	0-6	3-7	0-.8

III. ADDED RESISTANCE

A. At given $V/\sqrt{L}$, τ, $\bar{\beta}$ perform the following:

1. Obtain values of $(V/\sqrt{L})_m$ from Fig. 8
2. Obtain values of $(R_{AW}/wb^3)_m$ from Fig. 8
3. Calculate $V/\sqrt{L}/(V/\sqrt{L})_m$
4. Obtain $R_{AW}/(R_{AW})_m$ from Fig. 9
5. Multiply Lines 2x4 to get R_{AW}/wb^3
6. E corrections - Eqs. (1)-(3)
7. Multiply Lines 5x6 - Final values
8. Interpolate for given $H_{1/3}/b$

Line	$H_{1/3}/\bar{b}$ .2	.4	.6
1			
2			
3			
4			
5			
6*			
7			

B. Repeat procedure for other speeds

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*It will be necessary to plot E vs. $V/\sqrt{L}$ and interpolate for given speed.

WORK SHEET (continued)

IV. HEAVE AND PITCH MOTIONS

A. At given $H_{1/3}/\bar{b}$ obtain 1/10 highest values at $\tau = 4^o$, $\beta = 20^o$

1. Obtain heave or pitch
2. from Figs 10-14
3. Interpolate for correct $L/\bar{b}$
4. F. - Trim correction, Eq (4)
5. G. - Deadrise correction, Eq (5)
6. Final values - multiply lines 3x4x5
7. Interpolate for given speed

Line	$L/\bar{b}$	$V/\sqrt{L}$ 2	4	6
1.	4			
2.	5			
3.	$L/\bar{b}$			
4.				
5.				
6.				

B. Repeat procedure for other $H_{1/3}/b$

V. ACCELERATIONS

A. At given $H_{1/3}/b$ obtain avg. cg and bow accelerations at $\tau = 4^o$ and $\beta = 20^o$

1. Obtain η_{cg}
2. from Figs 15-17
3. Interpolate for correct $L/\bar{b}$
4. Obtain η_{bow}
5. from Figs 18-21
6. Interpolate for correct $L/\bar{b}$
7. Trim-Deadrise Correction, Eq (6)
8. Multiply Lines 3x7 for η_{cg}
9. Multiply Lines 6x7 for η_{bow}
10. Bow warp = .85 η_{bow}
11. Interpolate for given speed

Line	$L/\bar{b}$	$V/\sqrt{L}$ 2	4	6
1	4			
2	5			
3	$L/\bar{b}$			
4	4			
5	5			
6	$L/\bar{b}$			
7				
8				
9				
10*				

*May vary with bow shape

B. Repeat procedure for other $H_{1/3}/b$

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